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Front Cover: Indo-Pacific Humpback Dolphins (*Sousa chinensis*) engaging in social behaviour in Shoal Bay, Darwin Harbour. (Carol Palmer)

Back Cover: During surveys, the Swamp Tiger (*Danans affinis*) was abundant in Casuarina Coastal Reserve during the dry season. (Tissa Ratnayeke)

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Land snails associated with limestone outcrops in northern Australia – a potential bioindicator group

Michael F. Braby^{1,2}, Richard C. Willan³, John C.Z. Woinarski^{1,4}
and Vince Kessner⁵

¹ Biodiversity Conservation, Department of Natural Resources, Environment, the Arts and Sport, PO Box 496, Palmerston NT 0831, Australia. Email: michael.braby@nt.gov.au

² Research School of Biology, The Australian National University, Canberra, ACT 0200, Australia.

³ Museum and Art Gallery of the Northern Territory, GPO Box 4646, Darwin, NT 0801, Australia

⁴ Present address: PO Box 148, Christmas Island, WA, 6798, Australia.

⁵ 162 Haynes Rd, Adelaide River, NT 0846, Australia.

Abstract

Limestone outcrops and their associated monsoon vine thickets (dry rainforest) comprise a distinctive but poorly-known ecological community in northern Australia. Currently, most outcrops are poorly protected and lack adequate conservation management, the fire-sensitive rainforest vegetation is threatened by increased levels of landscape burning, and many outcrops are in need of restoration. Land snails obligatorily associated with this ecological community are particularly susceptible and have been identified as a potential bioindicator group for monitoring environmental health and for biodiversity conservation. These invertebrates are characterised by high levels of narrow-range endemism and beta-diversity. In the Tindall Limestone Formation at Katherine, NT, at least seven species of camaenid land snails have been recorded, of which five are endemic to the area. We describe a quantitative sampling protocol based on nocturnal counts to assess snail abundance in this formation at locations currently subjected to varying management regimes. Our preliminary observations indicate that snail assemblages in this area may be affected by an unbalanced grass-fire cycle driven by an increase in fire frequency and abundance of *Sorghum macrospermum*, an annual grass which is endemic to the Katherine region. At one site, for which snail abundance had been reported 30 years previously, it appears that this grass-fire cycle may have led to a dramatic loss of the understorey monsoon vine thicket habitat and the concomitant decline in abundance of a highly localised species of land snail. We conclude that the endemic land snails can be used as bioindicators for developing conservation management strategies of limestone-monsoon vine thicket associations, and recommend that this ecological community be better managed to minimise the incidence and intensity of fire.

Introduction

Rocky outcrops have been identified as an important ecosystem for biodiversity conservation, but they are under increasing threat from several processes and consequently are in urgent need of ecological management and restoration (Michael *et al.* 2010). These threatening processes include damage to microhabitats and changes to vegetation structure and composition. In northern Australia, patches of limestone (calcium carbonate) or dolostone (calcium carbonate with magnesium) occur throughout the monsoon tropics, often as scattered tors – loose aggregations of rocks in flat or gently undulating landscapes. These rocky outcrops, sometimes referred to as limestone karsts, are found mainly in the drier semi-arid areas (Figure 1) and frequently support pockets of deciduous monsoon vine thicket (i.e. dry rainforest) amidst a 'sea' of savanna woodland in the surrounding landscape (Russell-Smith 1991). Limestone outcrops have been identified as biodiversity 'hotspots' globally – although occupying a very small portion of the land surface, these ecosystems contain exceptionally high levels of species richness and endemism but are under imminent threat, particularly in the tropics of South-East Asia (Clements *et al.* 2006). They are also important in providing ecosystem services and resources, such as significant reservoirs of aquifer groundwater, guano and lime (Clements *et al.* 2006).

Limestone outcrops, although widespread in the Australian monsoon tropics, are neither as ubiquitous nor as structurally impressive as the more extensive sandstone formations, which support a rich assemblage of endemic plant, invertebrate and vertebrate biota (Woinarski *et al.* 2006). Nonetheless, limestone outcrops and their associated monsoon vine thickets are significant: some plant and invertebrate species appear to be restricted to this litho-vegetation association, which is among the most threatened ecological communities in northern Australia (Russell-Smith & Bowman 1992). In the 'Top End' of the Northern Territory (NT), most limestone outcrops are poorly protected within reserves and lack focused conservation management, and biological data are frequently deficient on which to make informed decisions on land use and/or to improve biodiversity conservation. The most extensive patches of the limestone outcrop estate in the Top End occur in upper Daly River and Victoria River districts, stretching from the Stuart Highway (between Katherine and Mataranka, NT) to the Great Northern Highway in the eastern Kimberley (between Kununurra and Halls Creek, WA) (Figure 1). However, most of this estate occurs on pastoral stations and very little is formally protected under Australia's National Reserves System, with only Gregory (Jutpurra) National Park in the NT conserving the most substantial extent of limestone. Kcep River National Park, NT, and the World Heritage Purnululu National Park, WA, also preserve significant patches of limestone, but the areas protected are relatively small in comparison and most of the respective patches occur outside the park boundaries (Figure 1). Three very small patches of limestone outcrop are also protected near Katherine at Elsey National Park and Cutta Cutta Caves and Flora River Nature Parks.

The purpose of this review is to highlight the conservation importance of limestone outcrops and their associated monsoon vine thickets in northern Australia, and to summarise the literature on the use of camaenid land snails as potential bioindicators for monitoring environmental health and for biodiversity conservation of this threatened ecological community. We also describe a sampling protocol to measure snail abundance based on a pilot survey near Katherine, and provide preliminary data on the possible effects of fire on land snails at two sites with contrasting fire history. On the basis of these observations we report an additional threat to this ecological community – invasion of grasses and the associated grass-fire habitat degradation cycle.

Land snails as bioindicators

The terrestrial invertebrate fauna of the limestone outcrop–monsoon vine thicket association in northern Australia has generally not been well sampled, but one significant component is the land snails. Studies in northern Queensland (Stanisic 1999 and references therein) and the Kimberley of Western Australia (see Solem 1991; Solem & McKenzie 1991 for reviews) have demonstrated a rich assemblage of land snails. These pulmonate molluscs, particularly the largest group, the family Camaenidae, show high levels of radiation, narrow-range endemism, high β -diversity and, in a few locations, high α -diversity (Stanisic 1999; Cameron *et al.* 2005; Köhler 2010a, b). Furthermore, the extended dry season of the Australian monsoon tropics poses special challenges for survival with reduced water availability for many months of the year. Limestone outcrops and associated monsoon vine thickets provide not only protection from desiccation during the protracted dry season but also from landscape fires, which occur frequently in the surrounding matrix of savanna woodland. Limestone outcrops in the Australian monsoon tropics are thus important refugia for land snail survival, containing stable microclimatic conditions, sufficient buffer from variations in temperature and moisture in both the short-term (i.e. harsh annual dry season) and long-term (i.e. evolutionary time) and protection from landscape fire. They also provide a ready supply of calcium during the short wet season when snails are active.

The notion that rock outcrops in the moister areas of Australia serve as important refugia for rainforest fauna was recently reviewed by Couper and Hoskin (2008). These authors documented a number of faunal groups and rainforest-associated lineages, including land snails, from eastern Queensland whose occurrence was highly dependent on the persistence of rocky outcrops. It was argued that rocky outcrops in the mesic areas of eastern Australia provide similar microclimatic conditions to rainforest in being cool, moist and largely sheltered from fire. During the Miocene and Pleistocene with the onset of increasing aridity, the geographic ranges of many rainforest-associated animals also contracted, some to isolated pockets such as rocky outcrops where suitable habitat/conditions persisted. The large-scale contraction of rainforest during the late Tertiary had profound effects on the fauna in terms of

extinction, distribution, population fragmentation and genetic diversity (Couper & Hoskin 2008). Thus, in the lower rainfall areas rocky outcrops and associated monsoon vine thickets act as historical refugia for the persistence and evolutionary development of rainforest-associated lineages that were formerly more widespread during wetter times.

The land snails of northern Australia have been proposed as a bioindicator group for monitoring environmental health and for biodiversity conservation of the specialised ecological communities in which they live (Stanisic 1999; Cameron *et al.* 2005; Slatyer *et al.* 2007). Indeed, land snails throughout the world have been used to identify priority areas for conservation based on their patterns of distribution, species richness and endemism (e.g. Bengtsson *et al.* 1995; Emberton 1997; Schilthuizen 2004; Schilthuizen *et al.* 2005; Sölymos & Fehér 2005; Clements *et al.* 2008; Horsák & Cernohorsky 2008; Wronski & Hausdorf 2008; Rundell 2010). Although the species-level taxonomy of the Australian fauna is far from complete, with many species still undescribed, most species can be readily sampled and identified to morpho-species based on their shell characteristics. In addition, many land snails are habitat specific, often have very small geographical ranges, and total species diversity within sites is not overwhelming. Moreover, many species of land snails in the NT have been listed as threatened and others are of conservation concern (Woinarski *et al.* 2007). These characteristics make land snails ideal indicators on which to develop better conservation management strategies and site protection, in a similar way in which some groups of insects have been used based on their patterns of occurrence, species richness and relative abundance (McGeoch 1998).

Less is known of the diversity, conservation status and threatening processes of land snails in the Top End of the NT than for northern Queensland and the Kimberley. However, two major threats facing land snails in the Top End have been identified: (1) increased fire frequency (during the dry season), and (2) increased trampling through high stocking rates of cattle (during the wet season) in critical breeding habitats (Woinarski *et al.* 2007). In addition, Pearson *et al.* (2009) concluded that predation by the invasive Cane Toad *Bufo marinus* may be a potential threat in some limestone habitats where the spatial and temporal activity patterns of both snails and toads overlap. A fourth potential threatening process is introduced weeds, especially pastoral grasses. These plants increase the fuel load and alter the fire regime, displace the native cover and organic matter, and increase exposure by reducing shelter/shade provided by understorey shrubs, and thus are detrimental to the overall feeding ecology and aestivation sites of snails. These extensive threats contrast with those in South-East Asia where mining (i.e. quarrying for cement production) is the primary threat facing land snails obligatorily associated with limestone karsts (Clements *et al.* 2006).

Land snails of the Tindall Limestone Formation, Katherine

The limestone outcrops in the Top End vary greatly in extent and degree of isolation, with the most extensive formations occurring in the upper Daly River district and Victoria River district, stretching from Katherine and Mataranka south-west to just west of the Western Australian border (Figure 1). Within this region, a substantial patch of limestone outcrop occurs around the town of Katherine, 275 km SSE of Darwin, that supports a number of endemic species of plants and animals (Daniel 2007). The outcrop is a more or less linear but discontinuous strip approximately 50 km long by up to 15 km wide oriented in a north-west to south-east direction around the Stuart Highway (Figure 2A). It comprises the largest significant patch of

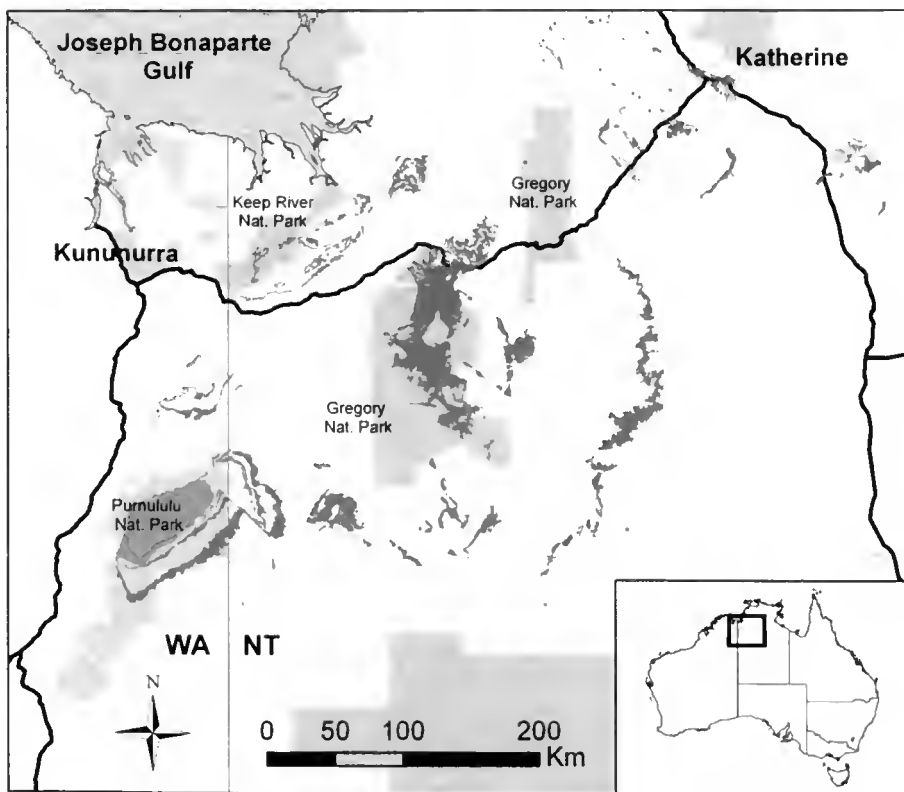


Figure 1. Map showing extent of limestone outcrops (grey shading) in the upper Daly River and Victoria River districts of the 'Top End', NT, and eastern Kimberley, WA. Areas shaded light green indicate areas protected under Australia's national reserve system. Major highways are indicated together with the towns of Katherine, NT, and Kununurra, WA.

limestone close to Darwin. Geologists refer to this outcrop as the Tindall Limestone Formation: it comprises sedimentary rock that was laid down millions of years ago by calcium-secreting marine organisms, but which has been subsequently uplifted and eroded (Sweet 1994). Specifically, the Tindall Limestone Formation is of Cambrian (Palaeozoic) age and composed primarily of grey massive, bioclastic, mottled, oncoid and cryptomicrobial limestone (Sweet 1994); in some areas the limestone is overlaid with sandstone, siltstone or claystone, or with sand and/or clayey and loamy soil. Within the outcrop, the limestone is highly fragmented and comprises numerous smaller patches or isolates of rock (Figure 2A). Relief is characteristically low, with most of the outcrop less than 10 m above the general land surface.

Systematic collections from the Tindall Limestone Formation at Katherine since 1979 (V. Kessner, unpublished data) have established that the area supports seven species of camaenid land snails. However, because the Tindall Limestone Formation has not been comprehensively sampled for land snails it is possible that additional species remain to be discovered. These snails represent the genera *Nanthomelon* Martens, 1860, *Setobandinia* Iredale, 1933 and *Torresitrachia* Iredale, 1939. The most diverse genus is *Torresitrachia* (Figures 3-4) with five species, all of which are narrow-range endemics restricted to the Tindall Limestone Formation (Willan *et al.* 2009, V. Kessner, unpublished data). Three of these species (*T. damini*, *T. alenae* and *T. wallacei*) occur only in the section north of the Katherine River (Figure 2B) and are considered to be threatened (Willan *et al.* 2009, V. Kessner, unpublished data), one species (*T. cuttacutta*) occurs in the southern section at Cutta Cutta Caves Nature Park, while another (*T. weaberama* species complex) is more widely distributed. The three species known from north of the Katherine River are all allopatric, separated by narrow breaks (< 2 km) in the extent of the rocky outcrop, and have exceedingly small distributional ranges (extent of occurrence varies from 1 km² to 20 km²). Given that the Tindall Limestone Formation is patchy in extent, *Torresitrachia* may well epitomise the local radiations at small spatial scales among land snails observed elsewhere in the world due to the combined effects of karst patchiness and poor dispersal ability (Schilthuizen *et al.* 2005; Clements *et al.* 2008; Wronski & Hausdorf 2008; Köhler 2010b).

Estimates of relative abundance

Land snails associated with limestone formations in the Australian monsoon tropics are active only during the short wet season, between about December and March, when they feed and breed. Moreover, these species forage only at night, rendering quantitative assessments of their relative abundance problematic. During the long dry season they aestivate as 'free sealers' (i.e. their aperture is sealed with an epiphragm) in the soil under large rocks, in crevices or deep in the soil litter, up to a depth of 0.3 m from the soil surface, where temperature conditions are cooler and stable and humidity is relatively constant.

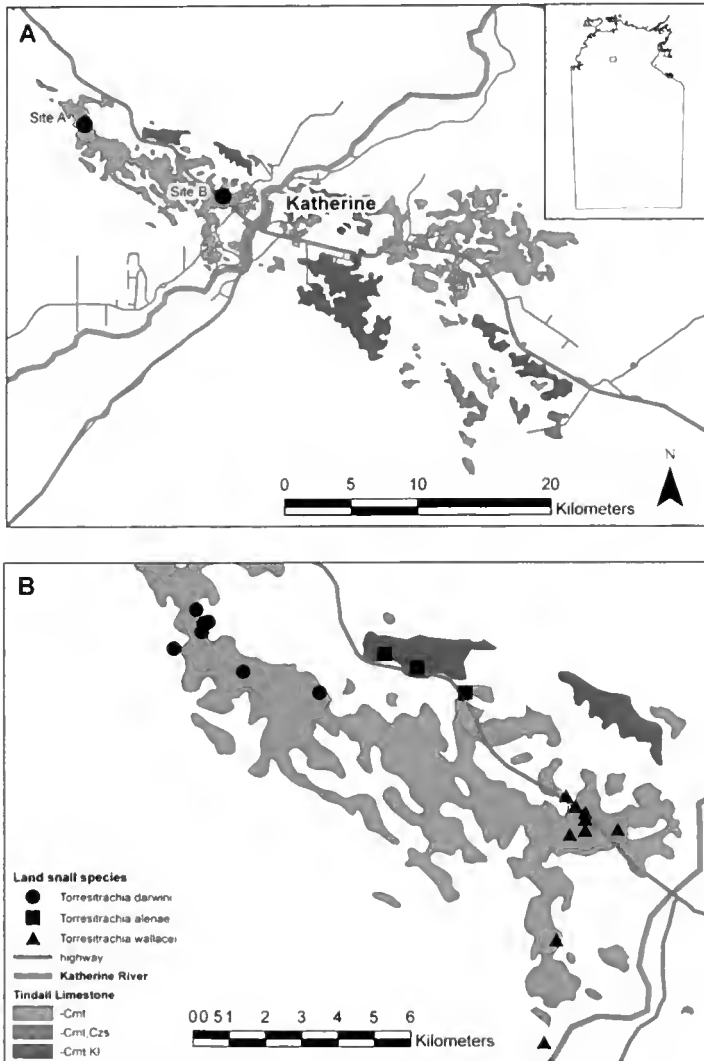


Figure 2. Extent of the Tindall Limestone Formation at Katherine: (A) location of study sites (insert map shows location within the Northern Territory, Australia); (B) known spatial distribution of three allopatric species of *Torresitrachia* land snails north of the Katherine River (part of the western section of Figure 1A). Geological strata are as follows: -Cmt, Tindall Limestone (grey massive, bioclastic, mottled, oncoïd and cryptomicrobial limestone, minor grey mudstone and maroon siltstone); Czs, residual soil and sand, clayey and loamy soils; Kl, quartz sandstone and ferruginous sandstone, silty sandstone, siltstone and claystone.

To our knowledge there have been no previous attempts to assess the relative abundance of land snails in the Australian monsoon tropics. During the summer monsoon wet season (January 2009) we undertook a preliminary study to test sampling methods of measuring snail abundance using strip transects. Two study sites were chosen north-west of Katherine (Figure 2A). One site was located at the Charles Darwin University Katherine campus (Site A: -14.3951° , 132.1443°); the second site was located 3 km north-west of Katherine River near the Stuart Highway (Site B: -14.4444° , 132.2377°). Each site supported different assemblages of small (average shell diameter ca. 13 mm) camaenid land snails. *Torresitrachia darwini* (Figure 3) occurred at Site A and we have collected this species from eight point sites, five of which are very close together (Figure 2B). *Torresitrachia wallacei* occurred at Site B and has been recorded from nine point sites, six of which are contiguous (Figure 2B). The habitat at Site A comprised low deciduous monsoon vine thicket on limestone and was long unburnt (Figure 5). Site B comprised disturbed open woodland on a ridge of limestone boulders and rubble scree in which the understorey was dominated by Katherine Sorghum *Sorghum macrospermum* (Figures 6-8). This site had been exposed to a frequent and intense fire regime (possibly on an annual basis) as evidenced by extensive fire scars on tree trunks, and dead trees.

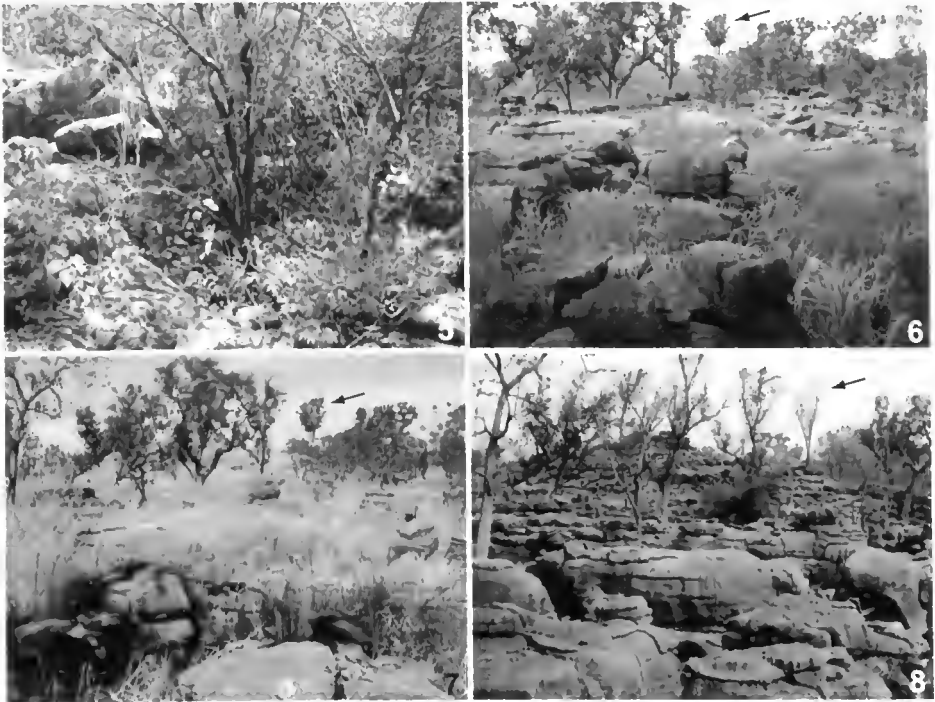
Four linear transects approximately 25 m in length were selected randomly at each site. Transects were marked with string and luminescent flagging tape. Adult snails (i.e. shell diameter > ca. 10 mm, with thickened outer lip) that were active on the ground and low-lying rocks were counted on either side of the transect at night (between 2020 and 2400 h) by two observers searching in parallel along the transect after rain. A third observer walked behind the two observers and recorded the number and perpendicular distance of snails from the centre of the transect. Each observer wore a headlamp. Juvenile snails (i.e. shell diameter < ca. 10 mm, with a thin outer lip) and dead shells were not counted. Counts were conducted on 25-26 January 2009 following several days of significant rainfall in the area. Intermittent rain also fell during the period when counts were made. Each transect took approximately 22 minutes to complete (i.e. a total of 90 minutes for each site).

The detectability of these small camaenid land snails was first assessed across two 25 m transects (Site A, 24 January) (Figure 9). This assessment showed that snails ($n = 42$) could be detected up to a perpendicular distance of 2 m on either side of the transect, but detectability tended to decrease sharply beyond 1.2 m. Hence, relative abundance of small-sized snails could be assessed using nocturnal counting techniques, provided that a team of three people working in optimal weather conditions was deployed. Subsequent counts of land snails (26 January) were then made to assess variability within and among sites across a replicated set of four 4 m x 25 m transects. At the site with a history of no recent fire (Site A), large numbers of *Torresitrachia darwini* were recorded ($\bar{x} = 49.8 \pm 34.54$ s.d.) although variability was high (coefficient of variation = 0.69). However, at the site with a history of recent fire (Site B), only one live snail of *T. wallacei* was detected ($\bar{x} = 0.3 \pm 0.50$ s.d.). Differences

in levels of relative abundance between the two sites were highly significant (Mann-Whitney U-test: $z = 2.56$, $P = 0.016$). At Site B, numerous dead shells were noted between and under the rock ledges. Incidental searches made during the daytime (27 January) revealed a few live snails at Site B; however, these snails were found only in small sinkholes with remnant vine thicket elements that were protected from fire. In contrast to Site A, there was a noticeable absence of organic matter on the ground and among the rocks and boulders at Site B.



Figures 3-4. *Torresitrachia* spp.: (3) *T. darwinii*; (4) *T. cutlacutta*. Both species are narrow-range endemics confined to the Tindall Limestone Formation.



Figures 5-8. Habitat of *Torresitrachia* spp. in the Tindall Limestone Formation: (5) long unburnt low deciduous monsoon vine thicket on limestone outcrop, habitat of *T. darwini* at Site A (Charles Darwin University Katherine campus); (6-8) disturbed open woodland on limestone outcrop, habitat of *T. wallacei* at Site B (3 km NW of Katherine River) showing seasonal changes in understorey layer, now dominated by *Sorghum macrospermum*, during the wet season (January 2009) (6), early dry season pre-fire (April 2009) (7), and mid dry season post-fire (July 2010) (8). Arrow indicates the same tree in figures 6-8.

Although based on only a single replicated sample for each site, the striking differences in land snail abundance between Sites A and B cannot be explained by differences in species behaviour, geological formation or sampling protocol. Sampling was standardised so that counts were made under the same conditions of observer, date and weather. However, we note that the two sites contrasted markedly in ground cover, with a flush of 1 m high annual grass at Site B, which may have reduced detectability of snails at this site. We consider that this contrast contributed only marginally to the observed differences in snail numbers between the two sites, given the intense scrutiny of the ground and ground layer vegetation that characterised the sampling of both sites.

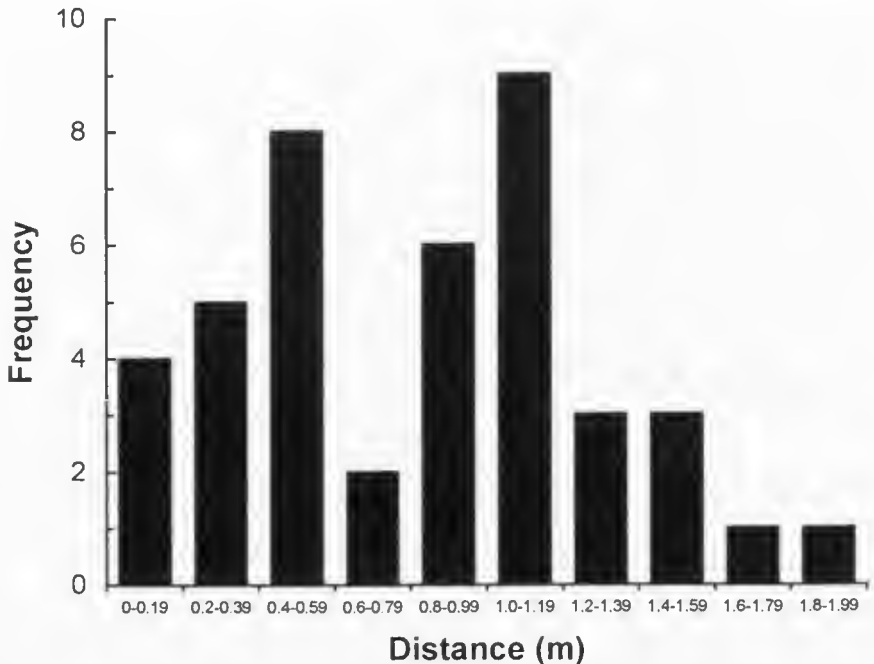


Figure 9. Detectability of *Torresitrachia darwini* measured at Site A based on 2 x 25 m transects. Snails ($n = 42$) were readily detected up to a distance of 1.2 m from the observer, but were not recorded at distances of greater than 2.0 m.

While there may well be differences in relative abundance among closely-related land snails, we consider the most significant factor accounting for the large discrepancy in counts between Site A (with numerous *Torresitrachia darwini*) and Site B (with only a single *T. wallacei*) was habitat quality, due to different fire regimes. Site A comprised old growth monsoon vine thicket with a closed canopy and the topsoil comprised a deep cover of organic matter, and there was no evidence of recent fire history. In contrast, Site B comprised woodland with an open canopy and its topsoil was devoid of organic matter and leaf litter. The latter site was also heavily invaded by annual sorghum and showed signs of high fire frequency as evidenced by dead trees and extensive fire scars on tree trunks. The presence of numerous dead shells indicated that snails were formerly abundant at Site B. Indeed, when *T. wallacei* was first recorded at this exact site 30 years ago, it was noted to be common (V. Kessner, unpublished data). Comparison of the extent of vegetation at Site B, based on aerial photographs taken in 1965 with those in 2010, revealed no detectable change in canopy tree cover. However, when V. Kessner (unpublished data) visited the site in the late 1970s he noted that the ground layer was shrubby and dominated by vine

thicket vegetation with little grass. More significantly, *Sorghum macrosperrum* was absent and there was little evidence of recent fire at that time. Hence, the major change to the habitat at Site B over the past 30 years appears to have been a substantial increase in grass biomass in the ground layer, most notably *S. macrosperrum*, and the concomitant decrease of a monsoon vine thicket shrub-layer. The estimated extent of occurrence of *T. wallacei* is less than 5 km² (Willan *et al.* 2009) and our field observations indicated that its entire habitat has been invaded and substantially altered by this grass.

Discussion

Land snails are sensitive to desiccation, have poor tolerance to high temperatures, low dispersal ability and have little capacity to escape fire, especially during the dry season when they are aestivating. In theory, land snails should be adapted to the 'natural' fire regime, that is, a proportion of snails aestivating should be able to survive the effects of fire, particularly those deep in the soil under rocks. However, if the burning regime is on an annual basis, then snail populations may have little or no opportunity to recover. Indeed, Stanisic (1999) cautioned that fire poses a serious threat to land snails and other invertebrates associated with monsoon vine thicket in Queensland, and several studies of land snails elsewhere in the world have shown that regimes of frequent and/or intense fires adversely affect species richness and/or abundance (Nekola 2002; Kiss & Magnin 2006; Santos *et al.* 2009). Moreover, frequent burning reduces the soil's organic litter layer on which land snails depend, which may take many years to accumulate. In central North America, Nekola (2002) concluded that fire intervals of more than 15 years were required to maintain the health and diversity of grassland land snail communities. In the Top End, the fire frequency or interval between fires required for monsoon vine thicket on limestone outcrops to accumulate sufficient organic matter for land snail survival is not known, but is probably of the order of several decades. These habitats were rarely if ever burnt by the indigenous Aborigines and were probably burnt irregularly via natural means such as lightning strikes.

Sorghum macrosperrum is a very tall (4 m) native annual grass and is endemic to the Katherine district of the Top End (Lazarides *et al.* 1991). It is restricted to limestone outcrops, favouring ridges of pavement, boulder and rubble serot landscape (Daniel 2007). Unlike a set of introduced pasture grasses – including Annual Mission Grass *Pennisetum pedicellatum* and Perennial Mission Grass *Pennisetum polystachion* – it has not been identified as an environmental weed that is posing a major threat to ecosystems in the NT. These exotic invasive pasture grasses can drive serious ecological changes through alteration of the fire regime (Kean & Price 2003) operating in a positive feedback interaction known as the 'grass-fire cycle' (D'Antonio & Vitousek 1992; Rossiter *et al.* 2003). In this cycle, invasion of the alien grass increases the fuel load, which increases the fire severity (frequency and/or intensity); the altered fire regime leads to increased disturbance and decreased tree cover, which then facilitates further

weed invasion. The increased intensity and extent of fires may lead to penetration and then diminution of some particularly fire sensitive habitats such as monsoon forest (D'Antonio & Vitousek 1992; Kean & Price 2003). It appears that repeated fires near the Katherine River have created an unbalanced grass-fire cycle for *S. macrospermum* similar to that reported for many invasive grassy weeds, and that this cycle has led to a dramatic loss of the understorey monsoon vine thicket habitat and the concomitant decline in abundance of *Torresitrachia wallacei*, a highly localised species of land snail. Further replicated sampling is needed to test this hypothesis. However, given the narrow-range endemism of land snails in the Tindall Limestone Formation, localised species such as *T. wallacei* may well be facing imminent extinction unless there is better land management of the limestone outcrops at Katherine through fire suppression.

Daniel (2007) identified a number of threats impacting the Tindall Limestone Formation, including alteration of monsoon vine thicket by fire, habitat loss through housing development and weed infestation. More generally, Michael *et al.* (2010) identified two key threatening processes affecting rocky outcrops: damage to microhabitats (caused by several factors including high-intensity fires and trampling by livestock), and changes to vegetation structure and composition (brought about by several factors including altered fire regimes and invasion by exotic plants). The latter authors recommended that outcrops be protected from processes that cause damage to rock microhabitat and be monitored and managed for changes in vegetation structure. We endorse these proposals. For the Tindall Limestone Formation, we recommend that the endemic land snails be used as bioindicators to monitor changes in vegetation structure and composition by assessing changes in their relative abundance. In terms of management, we recommend that the incidence and intensity of fire in outcrops be minimised (with a burning regime > 15 years) to prevent destruction of the monsoon vine thicket habitat of land snails, and that buffer zones around limestone patches be established to prevent spread of dry season fires from the surrounding savanna woodland into the monsoon vine thicket.

In summary, the literature and our preliminary observations at Katherine suggest that camaenid land snails are an excellent bioindicator group for developing conservation management strategies of limestone outcrops and their associated monsoon vine thickets in northern Australia. This ecological community is under increasing threat, particularly from heightened landscape fire. There is an urgent need to survey all limestone patches within the Tindall Limestone Formation at Katherine, and outcrops elsewhere in the Top End (Figure 1), to collect baseline data on land snail composition, species richness, extent of occurrence, abundance and threatening processes. This information can then be used to develop the scientific basis for conservation management and restoration of this ecological community. In addition, because most species of land snails obligatorily associated with limestone outcrops are scientifically undescribed, taxonomic studies are also needed to fully document the fauna (Willan *et al.* 2009).

Acknowledgments

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Butterfly counts at Casuarina Coastal Reserve in the seasonal tropics of northern Australia

Donald C. Franklin

Research Institute for the Environment & Livelihoods,
Charles Darwin University, Darwin, NT 0909, Australia.
Email: don.franklin@cdu.edu.au

Abstract

Seasonal rhythms underlie most ecological phenomena, but the seasonality of butterfly assemblages in the monsoonal tropics of the Top End of northern Australia remains unquantified. I counted butterflies along a 2.9-km transect through the Casuarina Coastal Reserve near Darwin in northern Australia on 23 occasions during eight census periods over a 14-month period. Both the number of taxa and number of individuals peaked during the wet season, but the latter peak continued into the early dry season. The dry season troughs in activity were about 50% by taxa and 35% by number compared with wet season peaks. Eight taxa demonstrated clear seasonal peaks, four in the wet season, two in the late wet – early dry season and two in the dry season. Much remains to be learnt about the seasonality of butterflies in the Australian monsoon tropics.

Introduction

In highly seasonal environments, organisms that live for less than a year, such as most butterflies (Lepidoptera: Papilionoidea, Hesperioidea), may not be able to breed continuously. If they cannot, they must vary their life history among generations, with some stage undergoing diapause – a state of rest or reproductive inactivity. For example, adults of the Common Crow *Euploea corinna* enter reproductive diapause during the tropical dry season, aggregating in sheltered refugia (Monteith 1982) until new growth is available on their larval food plants (Canzano *et al.* 2003). In the seasonal tropics, considerable attention has been given to adult diapause as a mechanism for coping with the dry season (e.g. Jones & Rienks 1987; Braby 1995a; Pieloor & Seymour 2001; Canzano *et al.* 2006). However, there is limited literature on egg, larval or pupal diapause in the tropics, even though adults of some species are absent during the dry season (e.g. Hill 1999; Braby *et al.* 2010). Common and Waterhouse (1981) report pupal dormancy in Darwin populations of the Fuscous Swallowtail *Papilio fuscus* that may last for more than two years. Diapause has been documented in each life stage (egg, larvae, pupae, adult) in temperate-zone butterflies (Scott 1981 cited in Ehrlich 1988).

More generally, the seasonality of butterfly assemblages has been poorly documented in the seasonal tropics, including monsoonal northern Australia, and no clear general patterns are apparent. In less seasonal tropical areas, butterfly species richness and/or abundance may peak in the dry (Borneo – Hamer *et al.* 2005; north Queensland – Braby 1995b) or wet season (Brazilian Atlantic forest: Ribeiro *et al.* 2010), whilst in more intensely seasonal environments, there are reports of no seasonal peak (Brazilian cerrado – Pinheiro *et al.* 2002) or a peak in the wet season (Mexican tropical dry forests – Luna-Reyes *et al.* 2008, 2010).

In this paper, I present count data for butterflies at eight intervals over a 14-month period in the Casuarina Coastal Reserve near the city of Darwin in northern Australia. The Darwin area is warm to hot throughout the year. The mean annual rainfall of 1,700 mm includes an extended dry season in which rainfall is typically negligible for 5–7 months and often zero for 3–5 months (McDonald & McAlpine 1991).

Methods

Butterflies were censused using a “Pollard walk” (Pollard 1977). This is a fixed-width (line or strip) transect, as also employed extensively for the census of birds (Bibby *et al.* 1992), in which the observer walks at a slow, steady pace along a pre-determined line and counts butterflies within a fixed distance of the line. The method necessarily documents diurnal species and especially those that are active at the time of day the count is conducted and those that fly low, but is excellent for detecting common species even in closed forest environments (Sparrow *et al.* 1994).

In this study, a single transect 2.9 km-long was employed. The transect formed a loop through a range of habitats in the Casuarina Coastal Reserve (12°21'S, 130°53'E), Darwin, following either established walking trails or the mown grassy edge to coastal vine-forest. The habitats sampled were:

- coastal vine-forest (the group 9, “semi-deciduous rain forests and vine thickets associated with a variety of well to excessively drained coastal and subcoastal landforms” of Russell-Smith (1991)) – 0.4 km;
- the ecotone between coastal vine-forest (as above) and mown dune grassland – 1.0 km;
- mangroves – 0.3 km;
- savanna woodland dominated by *Eucalyptus tetrodonta* and *Terminalia ferdinandiana* with a mostly perennial-grass understorey – 0.8 km; and
- parkland with mown exotic grasses and forbs and scattered remnant trees – 0.4 km.

None of the transect was subject to artificial watering, and the only natural external source of moisture in the dry season is tidal inundation of mangroves. Most of the savanna woodland was burnt in both years of the study.

Transect counts were conducted during eight periods, hereafter 'census periods', over a 14-month period from late July 2008 to late September 2009. Three transect 'counts' were undertaken in each census period (2 only in the 4th census period, Jan. 2009). The median (range) of intervals between census periods (median date of counts) was 57 (49–76) days and between counts within census periods was 7 (2–33) days.

Counts were conducted only on days with >50% sunshine during the late morning, no rain and at most a light breeze. I commenced counts between 1000 and 1030 h and they lasted 1.5 – 2 h including stoppage time to identify butterflies located whilst walking – butterflies were not counted if encountered only during stoppage time. With consecutive counts I alternated the direction of walk along the loop. Butterflies within or above a 5 m half circle in front of the observer were counted. At this distance (and without the use of net or optical aid) it was not possible to consistently identify all species so where necessary, species were aggregated into genera and morphotaxa, 29 of which were recognised (Appendix). For simplicity of terminology, the species, genus or morphotaxa recognised are hereafter referred to simply as 'taxa', names given to morphotaxa being presented in inverted commas.

Seasonal patterns were identified graphically after statistical screening. To evaluate the ability of the data to identify seasonal patterns, the number of species, number of butterflies, and number of each taxon present in 5 or more counts were compared across census periods with counts as replicates using non-parametric Kruskal-Wallis tests. Graphical results are presented only where the tests indicated significant differences among census periods with a probability less than 0.05.

Variation in assemblage composition among census periods was examined by Non-Metric Multidimensional Scaling in the software PC-Ord 4.01 (McCune & Mefford 1999). For each census period, 1 averaged counts of taxa. The six taxa present in only one census period were excluded. Mean counts of the remaining taxa were $\ln(x+1)$ -transformed to moderate the influence of a few abundant species. I employed the Bray-Curtis distance measure and allowed up to 400 iterations to ensure stable results. Fifty Monte Carlo runs in each of from 1–6 dimensions were used to generate stress from random data for comparison with stress from ordination results in a scree plot; this provided a quantitative basis for selecting the optimal dimensionality with which to present results.

Larval food plants were summarised into growth forms (herbaceous – grass, forb, vine; woody – shrub, tree, vine) for each taxon from information in Braby (2000). These are presented for all taxa in the Appendix and summarised in Table 1.

Table 1. Evidence of variation in the number of butterfly taxa, the number of butterflies, and the numbers of individual taxa that were present in more than five counts among eight census periods, along with larval food plant types for taxa. Definitions of morphotaxa are in the Appendix. Food plant types are generalised from the Appendix into the following categories: herbaceous (herb.) – grass, forb, vine; woody – shrub, tree, vine. * indicates $P < 0.05$; ** $P < 0.01$.

Response variable	Food plant type	No. of counts present (of 23)	Kruskal-Wallis H	Probability
No. of taxa		23	17.5	0.01 *
No. of butterflies		23	15.3	0.03 *
Hesperiidae				
"grass-darts" (Hesperiidae part)	grass	7	14.7	0.04 *
Papilionidae				
Fuscous Swallowtail (<i>Papilio fuscus</i>)	shrub	6	17.8	0.01 *
Pieridae				
Lemon Migrant (<i>Catopsilia pomona</i>)	tree	17	15.5	0.03 *
grass-yellows. (<i>Eurema</i> spp.)	forb & woody	20	18.1	0.01 *
Small Pearl-white (<i>Elodina walkeri</i>)	woody vine	23	15.0	0.03 *
"gull / albatross" (Pieridae part)	woody mixed	21	17.2	0.02 *
Nymphalidae				
Orange Ringlet (<i>Hypocysta adiante</i>)	grass	16	10.8	0.15
Orange Lacewing (<i>Cethosia penthesilea</i>)	woody vine	10	13.7	0.06
Varied Eggfly (<i>Hypolimnas bolina</i>)	forb	8	11.1	0.14
Blue Argus (<i>Junonia orithya</i>)	forb	6	13.3	0.07
Meadow Argus (<i>Junonia villida</i>)	forb	9	17.2	0.02 *
Lesser Wanderer (<i>Danaus petilia</i>)	woody vine	7	12.5	0.08
Swamp Tiger (<i>Danaus affinis</i>)	woody vine	18	20.1	0.005 **
Small Brown Crow (<i>Euploea darchia</i>)	woody vine	10	17.2	0.02 *
Common Crow (<i>Euploea corinna</i>)	woody mixed	23	15.8	0.03 *
Lycaenidae				
"small shrub lycaenids" (Lycaenidae part)	woody mixed	22	17.5	0.01 *
"small grass lycaenids" (Lycaenidae part)	herbaceous mixed	16	19.7	0.006 **

Results

Both the number of taxa and number of individuals varied significantly over time (Table 1, Figure 1). The number of taxa varied two-fold, peaking during the wet season. The number of butterflies varied three-fold and also peaked in the wet season, though the peak was later than for species richness and continued into the early dry season. A dramatic but variable increase in the number of butterflies in September 2009 was attributable to irruptions of “gull / albatross” (mostly Caper White *Belenois java*) and “small shrub lycaenids” (believed mostly to be the Purple Cerulean *Jamides phasei* associated with the flowers of *Millettia pinnata*).

Of the 17 taxa present in more than five counts, changes over time were demonstrable in 12 (Table 1), which is markedly more than the 5% that can be attributed to chance. Of these, four taxa peaked during the wet season (“grass-darts”, Fuscous Swallowtail, Meadow Argus, “small grass lycaenids”), two in the dry season (Swamp Tiger, “small shrub lycaenids”), and two in the mid-wet to early-dry season (grass-yellows, Small Brown Crow). The remaining four species displayed more diffuse patterns with no consistent trend (Lemon Migrant, Small Pearl-white, “gull / albatross”, Common Crow) (Figures 2, 3).

Interpretation of butterfly assemblages in a single dimension was the optimal outcome from ordination (Figure 4). Assemblages dichotomised on the basis of the wet and dry season, with a particularly large difference (2.16 of max. difference of 3.02) between consecutive census periods from 30 September to 20 November 2008.

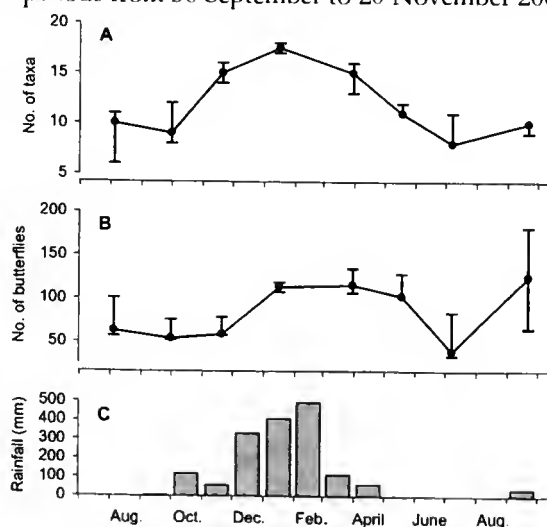


Figure 1. Variation over time from July 2008 to Sept. 2009 in: (A) the number of taxa/morphotaxa counted in Casuarina Coastal Reserve; (B) the number of butterflies counted in Casuarina Coastal Reserve; and (C) rainfall recorded during the study period at Darwin Airport. Data points in A and B are medians \pm range.

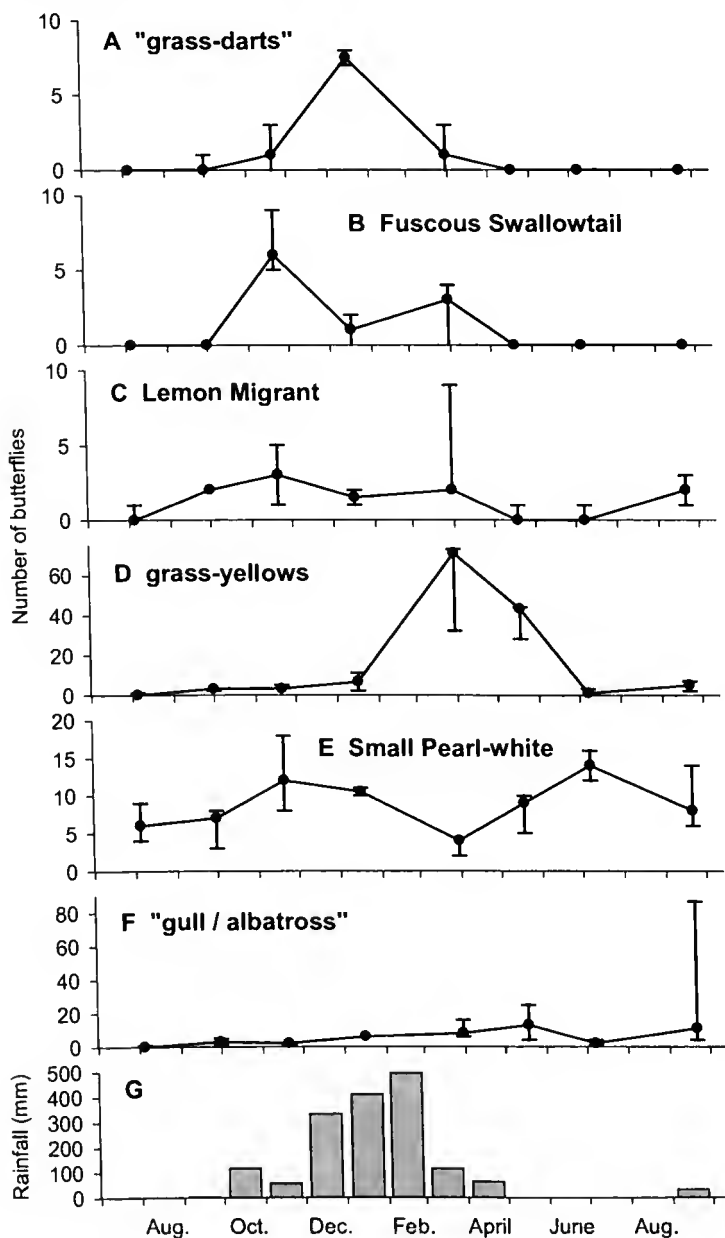


Figure 2. Variation over time in numbers (median \pm range) of six butterfly taxa: (A) Hesperidae; (B) Papilionidae; (C-F) Pieridae at Casuarina Coastal Reserve; and (G) rainfall at Darwin Airport from July 2008 to Sept. 2009. Note varying scales of abundance.

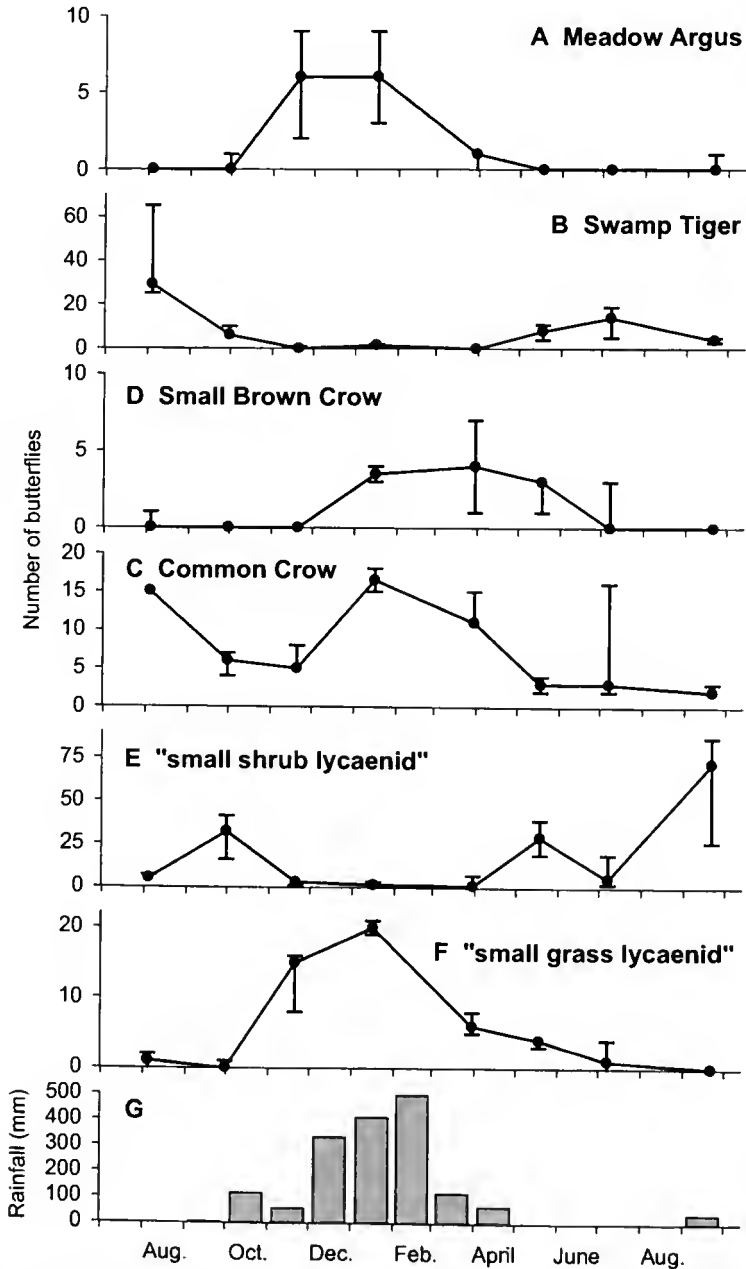


Figure 3. Variation over time in numbers (median \pm range) of six butterfly taxa (A-D – Nymphalidae; E-F – Lycaenidae) at Casuarina Coastal Reserve, and rainfall at Darwin Airport (G), from July 2008 to Sept. 2009. Note varying scales of abundance.

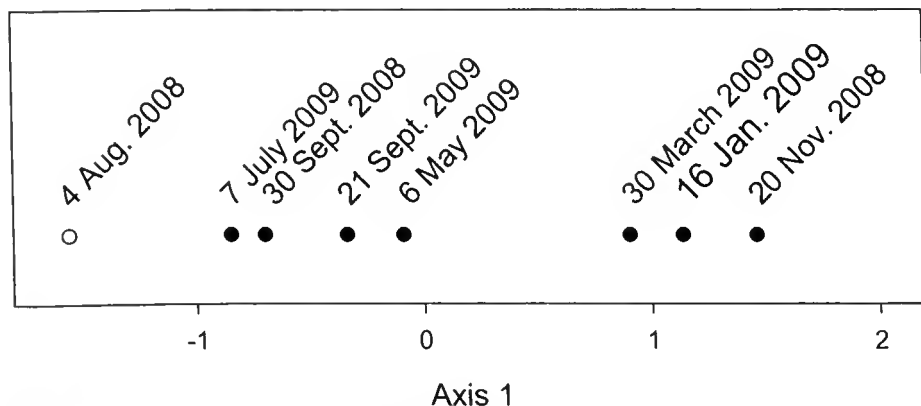


Figure 4. One-dimensional NMDS ordination of eight census periods based on assemblage composition (23 taxa). The median date of each census is shown. Final stress = 14.9, stable to one decimal place after 34 iterations.

Discussion

As one might anticipate in a highly seasonal environment where seasonality is primarily driven by rainfall, both species richness and the number of butterflies peaked during the wet season. This is expected for butterflies as the larvae of most species are dependent on fresh plant growth. The later peak and decline in the number of individuals compared to species richness may have occurred because populations of multivoltine species (those that undergo more than one generation per year) may accumulate with prolonged favourable conditions for breeding. Nevertheless, considerable butterfly activity persisted throughout the dry season. It is beyond the scope of this study to determine the biological basis for this continued activity: in theory, it could include persistence of diapausing adults, the ability to breed throughout the year (Jones & Rienks 1987; Braby 1995a), or migration into the study area (Dingle *et al.* 1999). Of note in this study is that taxa whose larvae feed, or mostly feed, on herbaceous plants, peaked in abundance in either the wet season ("grass-darts", Meadow Argus, "small grass lycaenid") or the wet-dry transition ("grass-yellows"). In contrast, all taxa with diffuse seasonal patterns have larvae that feed on shrubs, trees or woody vines, as do the two taxa that peaked during the dry season (Swamp Tiger, "small shrub lycaenids"). Although most woody plants in the region grow during the wet season, this is far from invariably so (Williams *et al.* 1997; Bach 2002).

My surveys are necessarily preliminary in that only a little over one annual cycle was investigated. It would be interesting to know how repeatable these patterns are – mosquito assemblages in the Darwin region exhibit strongly repeated annual cycles (Franklin & Whelan 2009). Further, my data suggests two taxa as prime candidates for

the investigation of non-adult diapause, "grass-darts" and Meadow Argus. To these may be added the White Albatross *Appias albina* (Braby *et al.* 2010), which is however, uncommon and thus less tractable as a research subject. None of these taxa are known or suspected to be migratory in the region.

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Appendix. Taxa/morphotaxa recognised in this study and their attributes.

This appendix is available at: <http://sites.google.com/site/ntfieldnaturalists/journal>.



Casuarina butterflies
(clockwise from above):
Lemon Migrant (TR),
Greenish Grass-dart (DB),
Orange Ringlet (DB),
Small Pearl-white (DB).



Right: Fuscous
Swallowtail
(TR).

Photographers:
DB - Deb
Bisa;
TR - Tissa
Ratnayake.



DNA analysis identifies *Solanum* from Litchfield National Park as a lineage of *S. dioicum*

Christopher T. Martine¹, Elizabeth M. Lavoie^{1,2}, Nicholas P. Tippery^{3,4}, F. Daniel Vogt¹, and Donald H. Les³

¹ Department of Biological Sciences,
State University of New York at Plattsburgh, Plattsburgh, NY, USA.

Email: christopher.martine@plattsburgh.edu

² Present address: Department of Cellular and Molecular Biology,
Stony Brook University, NY, USA.

³ Department of Ecology and Evolutionary Biology,
University of Connecticut, Storrs, CT, USA

⁴ Present address: Department of Biological Sciences,
University of Wisconsin-Whitewater, Whitewater, WI, USA.

Abstract

The uncommon reproductive system of dioecy is somewhat widespread in Solanaceae, being exhibited by members of five genera within this family. These members represent, however, only around 1% of species within the Solanaceae. The highest incidence of dioecy is found in the genus *Solanum*, where around 15 species have been described as consisting of populations in which individual plants are either “male” (staminate) or “female” (pistillate). Ten of these *Solanum* species, commonly known as ‘bush tomatoes’, are endemic to the Australian monsoon tropics. During recent fieldwork in the Northern Territory, non-reproductive collections were made of a morphologically distinct population of *Solanum* (*Solanum* sp. Litchfield I.D. Corrie 1428) from Litchfield National Park. We generated the first DNA sequences of these exceptional plants, amplifying the ITS (nuclear) and *trnK-matK* (chloroplast) DNA regions. Phylogenetic analysis comparing molecular data of *Solanum* sp. Litchfield with previously sequenced relatives infers that the taxon is closely allied to *S. dioicum*, a widespread species already considered to be morphologically diverse. However, we consider *Solanum* sp. Litchfield to represent a morphologically and geographically distinct taxon. Although all specimens collected to date lack reproductive features, the phylogenetic placement of *Solanum* sp. Litchfield infers that the species is likely to be dioecious, thus broadening our understanding of the distribution and circumscription of dioecious lineages of *Solanum* in Australia.

Introduction

Within the plant family Solanaceae, the highest abundance of dioecy (‘male’ and ‘female’ flowers occurring on separate plants) is recorded in the genus *Solanum*, with

around 15 species using this form of reproduction (Anderson & Symon 1989; Martine *et al.* 2006; Martine *et al.* 2009). Most (12) of the known (*c.* 16) dioecious solanums are included in subgenus *Leptostemonum*, which is known as the 'spiny solanums' (Miller & Diggle 2003; Martine *et al.* 2009). Ten of these species are found only in northern Australia (Anderson & Symon 1988; Anderson & Symon 1989), where they are known locally as 'bush tomatoes'. The geographic ranges of these ten species are more or less restricted to two regions: the Kimberley of Western Australia and the central Arnhem Land Plateau of the Northern Territory (Symon 1980; Martine & Anderson 2007; Martine *et al.* 2009).

All occurrences of dioecy in *Solanum* are exhibited through a 'cryptic' form in which populations within a species appear to be androdioecious (having male flowers on some plants and hermaphrodite flowers on others). However, these species have been shown to be functionally dioecious because the pollen produced by morphologically hermaphrodite flowers is inaperturate (*i.e.* without pores) and incapable of germination, making them unable to contribute to male reproductive function through fertilization (Anderson & Symon 1989; Martine *et al.* 2009; Martine *et al.* 2010). Thus, individual dioecious bush tomatoes are either 'male' (with clearly staminate flowers bearing only stamens) or 'cryptically female' (with conspicuous pistils and stamens producing non-functional pollen).

Because of the frequency of dioecy in Australian *Solanum*, and its occurrence over a restricted geographic region, the bush tomato group has been treated as a model system in which to study the evolution of dioecy, especially because potential transitional reproductive states are also present in the lineage (Anderson & Symon 1989). Current work in *Solanum* subgenus *Leptostemonum* has also focused on the apparent recent radiation of Old World 'spiny solanums' (Levin *et al.* 2006; Bohs *et al.* 2007) and it is clear that the evolutionary relationships among most Australian, Asian, and African species of *Solanum* subgenus *Leptostemonum* remain difficult to elucidate without a comprehensive sampling of taxa and the use of more informative gene regions than currently used (Bohs *et al.* 2007).

Although recent work by Martine and colleagues (Brennan *et al.* 2006; Martine *et al.* 2006; Martine & Anderson 2007; Martine *et al.* 2009) has built on the outstanding contribution of Symon (1980), the taxonomy and circumscription of dioecious Australian solanums is still in flux. Notably, several distinct populations of dioecious solanums with uncertain taxonomic affinity are known and/or have been collected from the Kimberley, the central Arnhem Plateau and adjacent areas (D. Symon, pers. comm). This includes a population from Litchfield National Park that has long been suspected by botanists at the Northern Territory Herbarium (DNA) to be a distinct taxon based on its slender leaves, limited armature and diminutive size (Figure 1). This population has been designated as *Solanum* sp. Litchfield (I.D.Cowie 1428) (Short *et al.* 2011). Collections of non-reproductive material of *Solanum* sp. Litchfield have been

made by K.G. Brennan, I.D. Cowie, J.L. Egan, J.O. Westaway and others and accessioned at the Northern Territory Herbarium.

In the absence of specimens with flowers and fruit, this study uses DNA sequence data to evaluate the phylogenetic position of *Solanum* sp. Litchfield and to assess whether it corresponds to a described taxon or represents a previously undescribed taxon.



Figure 1. Adult non-reproductive specimen of *Solanum* sp. Litchfield I.D.Cowie 1428 on sandstone rockpile along east side of Florence Falls Rd., Litchfield National Park. (F.D. Vogt)

Methods

Understanding the phylogenetic placement of *Solanum* sp. Litchfield requires two steps: (1) obtaining DNA sequence data, and (2) appending the new DNA sequences to available data from related species (Table 1). The two DNA regions selected for this study were the ITS (nuclear) and *trnK-matK* (chloroplast) regions, which Martine et al. (2009) used to estimate phylogenetic relationships among about 25 closely-related species of *Solanum* endemic to Australia.

Table 1. Previously sequenced Australian dioecious species of *Solanum* (Martine et al. 2009) used for comparison with new sequences generated for *Solanum* sp. Litchfield, including an undescribed species from the Kimberley coast (*S.* sp. 'Longini'). The dataset consists of nine andromonoecious species from Australia included by Martine et al. (2009) in previous phylogenetic studies.

Dioecious species	Center of distribution	GenBank
<i>S. asymmetriphyllum</i>	Kakadu	EU983570
<i>S. carduiforme</i>	Kimberley/NT	EU983556
<i>S. dioicum</i> (typical)	Kimberley	EU983553
<i>S. dioicum</i> (Tanami Desert form)	Kimberley	EU983554
<i>S. leopoldensis</i>	Kimberley	EU983560
<i>S. petraeum</i>	Kimberley	EU983559
<i>S. sejunctum</i>	Kakadu	EU983568
<i>S. tudununggae</i>	Kimberley	EU983552
<i>S.</i> sp. 'Longini'	Kimberley	EU983561

Collections

Field collections (Table 2) were made in May 2009 in Litchfield National Park, in localities suggested by staff botanists in the Northern Territory Herbarium. Voucher specimens were pressed for herbarium accessioning, while fresh leaf samples were placed in individually labeled envelopes partly filled with silica gel (to quickly preserve leaves to be used for later DNA extractions).

DNA isolation and PCR amplifications:

DNA was isolated from silica-dried leaf material using a modified standard protocol (Doyle & Doyle 1987). Each gene region was PCR-amplified using primers for the ITS region and *trnK-matK* region (Table 3) using the protocols described by Martine et al. (2006, 2009). Because of the large size of the *trnK-matK* target region, primers were used that would create overlapping fragments to be assembled into one large contiguous sequence. Presence of PCR product was confirmed on 1% agarose gel.

Table 2. Collections of *Solanum* sp. Litchfield made during the 2009 expedition. All collections were made from within Litchfield National Park.

Collection no.	Locality information	DNA code	GenBank accession #	
			ITS	<i>trnK-matK</i>
CTM 1751	Sandstone rockpiles along east side of Florence Falls Rd, 0.5 km N of junction with Litchfield Park Rd. 13°07.531'S, 130°48.140'E	01A	JN098472	JN098476
CTM 1752	Near above	01B	JN098473	JN098477
CTM 1753	Sandstone rockpiles in vicinity of 'The Lost City,' 150-200 m SE of car park. 13°13.137'S, 130°44.216'E	04A	JN098474	JN098478
CTM 1754	Near above	04B	JN098475	JN098479
CTM 1756	Sandstone rockpiles just south of junction of Litchfield Park Rd. and Florence Falls Rd. 13°07.664'S, 130°48.305'E	N/A		

Table 3. Gene regions examined and associated primer sequences.

Gene Region	Primer Sequence
<i>ITS-4</i>	TCCTCCGCTTATTGATATGC
<i>ITS-5</i>	GGAAGTAAAAGTCGTAACAAGG
<i>68F</i>	TCTTTCAGGAGTATATTTATG
<i>1556R</i>	CCTTGATACCTAACATAATGC

Cycle sequencing

Each PCR reaction was cleaned by adding 0.5 µL of a 1:5 dilution of ExoSAP-IT® (Affymetrix, Inc., Santa Clara, California, USA) to 1.0 µL of PCR product. Cycle sequencing was performed with the same sets of forward and reverse primers used in the PCR reactions using the method described by Martine *et al.* (2006). Raw DNA sequences were then recorded using an ABI Prism® 3100 automated sequencer (Applied Biosystems, Foster City, California, USA).

Sequence alignment and phylogenetic analysis

Editing of raw sequences was performed using 4Peaks software (Griekspoor & Groothuis 2005) for ITS and CodonCode Aligner, version 1.3.1 (CodonCode Corporation, Dedham, Massachusetts, USA) for *trnK-matK*. The two gene regions

were combined to form a dataset of more than 2600 base pairs. A manual alignment was performed in MacClade (Maddison & Maddison 2005) and then exported into PAUP* (Swofford 2002) for phylogenetic analyses using Maximum Parsimony. Bootstrapping was performed with 500 replicates.

Results

The four accessions of *Solanum* sp. Litchfield included in the analysis form a well-supported (93% bootstrap) clade nested within the 'Kimberley Dioecious' clade (Martine *et al.* 2006), a group of several sub-arid and monsoonal dioecious spiny solanums closely allied with *S. dioicum* that occur throughout the Kimberley and sandstone country of the NT. The distinctness of *Solanum* sp. Litchfield was apparent even when each gene region was analyzed separately, but we have chosen to present the relationships based on the combined dataset (Figure 2) so as to remain consistent with the expanded treatment of Martine *et al.* (2009). Although the small range of *Solanum* sp. Litchfield is geographically close to Kakadu National Park, the taxon does not appear to be closely related to *S. sejunctum* and *S. asymmetriphyllum*, the two members of the dioecious 'Kakadu clade' as defined by Martine *et al.* (2006).

Discussion

Phylogenetic analysis using the ITS and *trnK-matK* gene regions supports the distinctness of the *Solanum* population from Litchfield National Park (Figure 2). This conclusion is based on the fact that the DNA sequences extracted from all four collections of *Solanum* sp. Litchfield are shown to be more similar to one another than any of them are to the related species of *Solanum* included in the analysis. The phylogeny presented in Figure 2 clearly illustrates this, with moderate level of support provided by bootstrap analysis. Our analysis using these two DNA regions, one nuclear and one chloroplast, provides further evidence that *Solanum* sp. Litchfield is closely allied to *S. dioicum* and other taxa from the Kimberley region.

Although additional evidence may eventually validate *Solanum* sp. Litchfield to be a distinct species, the current lack of data regarding its reproductive structures allows only for its provisional recognition as a lineage within *S. dioicum*. Prior to our study, *S. dioicum* already was considered to include at least two divergent lineages, one of which (*Solanum dioicum* Tanami Desert form) is known from the eastern Kimberley and is distinct in having broad, densely white-tomentous leaves and heavily armed stems and calyces. The taxonomic disposition of lineages within *S. dioicum* has been difficult to resolve because populations appear to intergrade morphologically (Symon 1980) and because sampling for recent molecular systematic studies has not been broad enough to capture the extent of variation within the complex. A complete taxonomic treatment of *S. dioicum* (including *Solanum* sp. Litchfield) must address the disposition of *Solanum dioicum* Tanami Desert form and other unresolved populations in order to maintain a cladistically consistent *S. dioicum*.

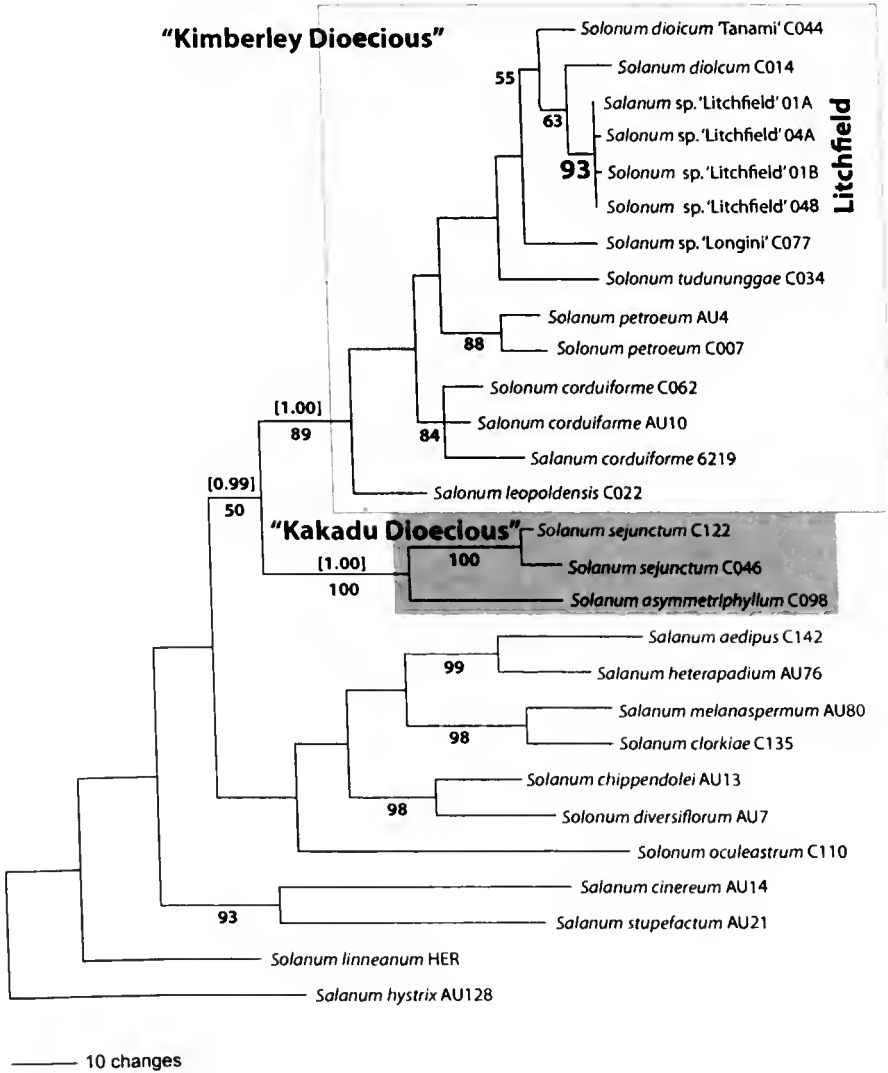


Figure 2. One of a set of best Maximum Parsimony trees depicting the relationship of *Solanum* sp. Litchfield (four accessions) to other dioecious and andromonoecious Australian spiny solanums inferred from concatenated ITS and *trnK-matK* DNA regions. Numbers below branches are Bootstrap values (500 replicates). Bracketed support values at three key nodes are Bayesian posterior probabilities generated for the same groupings by Martine *et al.* (2009).

Field observations of *Solanum* sp. Litchfield provided additional features that link it with *S. dioicum*. The grey and woody stems of *Solanum* sp. Litchfield are sparsely armed (though more prickly toward the base), whereas the leaves lack armature entirely. The foliage bears a short, rusty-red tomentum and a general coloration that is light green and slightly red- or yellow-tinged. Individual plants reach a height of approximately 40 cm, with the largest stems growing to 4-5 mm in diameter. Prickles are straight, slim, and 2-3 mm long.

Like many Australian congeners (Symon 1980), *Solanum* sp. Litchfield is associated with sandstone rockpiles, growing in low outcrops in sand between the rocks and boulders. Surveys of populations on and around rockpiles led to the observation that most rockpile populations are at least partly clonal, with ramets connected via underground runners 10-12 cm below the surface. This is a habit common in *S. dioicum*, *S. petraeum*, and other similar members of the 'Kimberley Dioecious' clade (Symon 1980; Martine, pers. obs.). Much like these species, *Solanum* sp. Litchfield resprouts from runners following fire, with new post-fire growth being more vigorous and heavily armed in comparison to older growth (Martine & Vogt, pers. obs.). The three localities referenced here for *Solanum* sp. Litchfield are areas where controlled fires have been periodically set to avoid mass conflagrations, a management scheme that appears to benefit the species. Vigorous growth was witnessed where fires had recently burned (localities near Litchfield Park Road, Table 2), whereas plants appeared to be declining in vigor in unburned sites around The Lost City.

The close relationship of a dioecious *Solanum* from the Northern Territory to a group of species largely restricted to the Kimberley is interesting, but not a unique circumstance. *Solanum carduiforme*, also a member of the 'Kimberley Dioecious' clade (Figure 2), is currently known from four widely disjunct localities running from the eastern Kimberley to western Queensland, including a single population recorded by W.R. Barker and C.T. Martine in 2004 at Keep River National Park, NT. A recent flora survey at Bullo River Station in the eastern Kimberley, NT, by staff at the Northern Territory Herbarium resulted in collections of specimens that closely resemble both *S. carduiforme* and *Solanum* sp. Litchfield (I. Cowie & J. Westaway, pers. comm.). If confirmed, these would represent significant new locations for each taxon.

Although *Solanum* sp. Litchfield has been provisionally recognised as a distinct taxon by botanists at the Northern Territory Herbarium for some time, its taxonomic affinity and its reproductive biology have not previously been determined. A more complete understanding of *Solanum* sp. Litchfield and its potential designation as a new species await the collection and examination of adequate specimens, especially those with flowers and fruits. In addition, future work, including scanning electron microscope photography and greenhouse-crossing experiments, are needed to confirm that *Solanum* sp. Litchfield, like the other dioecious bush tomatoes, is functionally dioecious via the production of inaperturate pollen grains in

morphologically hermaphrodite flowers. This work necessitates collection of fruits and seeds to be used in culturing the species.

The most important work, however, will include a broad morphological and molecular survey of the taxonomically problematic *Solanum dioicum* species complex, of which *Solanum* sp. Litchfield is a member. This survey, currently underway, may provide the evidence required to describe *Solanum* sp. Litchfield as a distinct species. In the meantime, molecular recognition of *Solanum* sp. Litchfield provides evidence for its affinity to *Solanum dioicum*, broadens our understanding of the *S. dioicum* complex, and expands the known range of the 'Kimberley Dioecious' clade.

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Shallow water foraging using a shoreline boundary by the Indo-Pacific Humpback Dolphin *Sousa chinensis* in northern Australia

Scott D. Whiting

Marine Biodiversity Group,
Department of Natural Resources, Environment, the Arts and Sport,
c/o Arafura Timor Research Facility, Casuarina, NT 0811, Australia.
Present Address: Department of Environment and Conservation,
17 Dick Perry Av., Kensington, WA, 6151, Australia.
Email: scott.whiting@dec.wa.gov.au

Abstract

Observations of two specialised feeding behaviours (strand-feeding and repetitive tail-slapping) by the Indo-Pacific Humpback Dolphin *Sousa chinensis* during one feeding event in northern Australia are reported for the first time. These observations provide insights into the type of foraging habitats and niches of this shy coast dwelling species. The feeding behaviours are compared with similar behaviours of other toothed whales and dolphins.

Introduction

Several species of Odontocetes (toothed whales and dolphins) are known to feed in shallow water using a variety of behaviours (Hoese 1971; Lopez & Lopez 1985; Peddemors & Thompson, 1994; Guinet & Bouvier 1995; Wells *et al.* 1999). For coastal dolphin species, the shoreline boundary and shallow water can limit prey escape and reduce the need for large hunting groups and fast pursuits (Wells *et al.* 1999). Given the numerous species of Odontocetes throughout the world, the variety of prey types and the vast range of shallow water habitats utilised, there is a surprisingly limited range of feeding behaviours described in the literature.

This note reports three shallow water foraging behaviours (milling, strand-feeding and modified tail-slapping) (Connor *et al.* 2000; Mann & Sargeant 2003) used by the Indo-Pacific Humpback Dolphin *Sousa chinensis* during one foraging event in northern Australia. These observations highlight the diversity of foraging behaviours used by this species, which is known to inhabit turbid coastal and estuary waters.

Observations

On 1st May 2007, while standing on the shore of Cape Van Diemen at Melville Island, Northern Territory (11°10'39"S, 130°22'22"E), I observed five *Sousa chinensis* close to the western shoreline, a location which is sheltered from prevailing winds. Sighting conditions were good, sea conditions and the sea state was calm (Beaufort 0), and the water was relatively turbid. The observations were recorded one hour after low tide between 1030 h and 1050 h.

Initially, all individuals were observed between 5 m and 15 m offshore, in water estimated to range in depth from 0.7 m to 2.0 m and displayed behaviour consistent with common fish chasing milling behaviour (Mann & Sargeant 2003; Para 2006). This behaviour involves individuals taking slow dives, then re-surfacing, followed by short bursts of speed and with all forays beginning and ending in different directions.

After approximately five minutes of observation, two individuals on five occasions charged aggressively towards the shoreline, producing bow waves approximately 10 – 20 cm high. The dolphins did not swim together, but swam towards the shore in succession. Just before they reached the shore, they orientated themselves parallel to the shoreline creating a wave to wash up the sandy beach (Figure 1). On two of these occasions the dolphins were left partially stranded with more than half their bodies exposed. On these occasions, the individuals arched their bodies and angled their heads towards the shore presumably to search for beached prey. On the three other occasions the individuals swam into shallow water that restricted their ability to swim away easily. There did not appear to be any fish forced out of the water during any of these episodes.

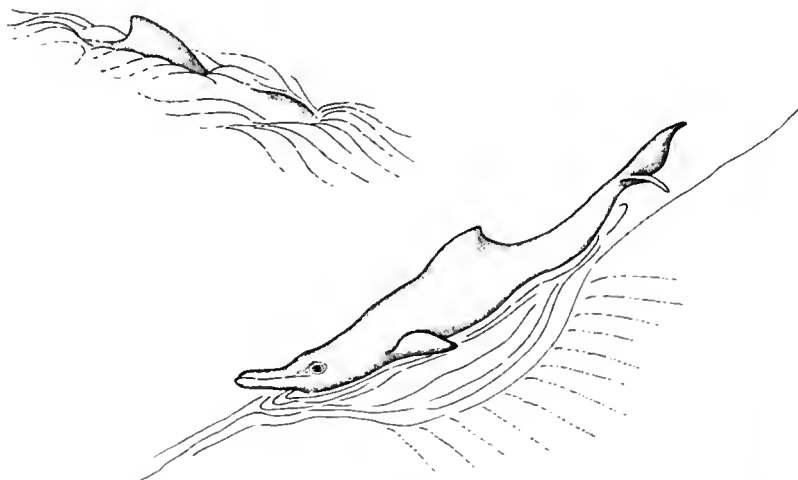


Figure 1. Indo-Pacific Humpback Dolphin exhibiting strand-feeding behaviour.

In contrast, a third dolphin displayed different behaviour; it swam slowly and perpendicular towards the shore and repeatedly raised its tail fluke out of the water and slapped it back on the surface of the water in quick succession, making an audible sound and surface splash (Figure 2). On one occasion five tail slaps were used in succession before the dolphin u-turned away from shore. The dorsal fin remained out of the water between all five tail-slaps. All dolphins seemed unaware of, or oblivious to, my presence.



Figure 2. Indo-Pacific Humpback Dolphin tail-slapping behaviour.

Discussion

The three foraging behaviours reported here include: (1) milling, (2) beach or strand-feeding and (3) tail-slapping. Milling behaviour is characterised by irregular surface intervals and individuals continually change direction with each dive and breath (Mann & Sargeant 2003; Para 2006). Beach or strand-feeding and tail-slapping have not previously been reported for this species (Para 2006).

The observed strand-feeding behaviour is similar to that described by Mann and Sargeant (2003) where bottlenose dolphins chase fish in shallow water and launch fully or partially out of the water to catch the fish. Strand-feeding has been recorded for *Sousa plumbea* in Mozambique whereby dolphins cooperatively or individually chase

fish out of the water, onto mud banks and then beach themselves to capture the prey (Peddemors & Thompson 1994). Interestingly, the geographical ranges of *Sousa plumbea* and *S. chinensis* do not overlap and high genetic divergence occurs between the African populations of *S. plumbea* and the Australian populations of *S. chinensis* (Frère *et al.* 2008). This shallow water foraging behaviour has also been recorded for common bottlenose dolphins *Tursiops truncatus* in Georgia (Hoese 1971) and South Carolina (Rigley 1983) and bottlenose dolphins *Tursiops* sp. in Western Australia (Sargeant *et al.* 2005). However, *S. chinensis* at Cape Van Diemen did not display the full exposed beaching and capture of beached fish described by Sargeant *et al.* (2005). It is interesting that similar strand feeding behaviour has been recorded among the genera *Orcinus* (Guinet & Bouvier 1995), *Sousa* (Peddemors & Thompson, 1994) and *Tursiops* (Hoese 1971; Rigley, 1983).

The tail-slapping behaviour observed at Cape Van Diemen differed from other tail-slapping behaviours such as the kerplunking behaviour described for bottlenose dolphins *Tursiops aduncus* in Western Australia (Connor *et al.* 2000; Nowacek 2002). Kerplunking is a specialised behaviour that involves the body being almost vertical with the tail held fully out of the water and then pivoting before the tail is brought down on the surface of the water. During each tail-slap the tail is pushed down and forward into the water producing a cloud of bubbles that possibly aid in scaring or detecting fish in bottom grubbing or played a role a social function (Connor *et al.* 2000). The tail-slapping behaviour of *S. chinensis* at Cape Van Diemen is dissimilar to the percussion kerplunking recorded in Western Australia (Connor *et al.* 2000), but may be used for the same purpose of herding or scaring fish similar to the behaviour used by bottlenose dolphins in Florida (Hamilton & Nishimoto 1977). The sequential surface tail-slapping behaviour recorded at Cape Van Diemen is not listed as one of the foraging behaviours for *S. chinensis* (Nowacek 2002; Mann & Sargeant 2003; Karczmarski *et al.* 2000; Parra 2006). There was no evidence of fish-whacking to stun prey with the tail fluke that has been observed in bottlenose dolphins and common dolphins (Wells *et al.* 1999; Nowacek 2002; Neumann & Orams 2003). Both strand-feeding and tail-slapping behaviours would be appropriate to herd fish into the shallow water and against the shoreline boundary to increase prey density and catch efficiency as suggested by Heimlich-Boran (1988). These observations provide some insights into the range of foraging behaviours of this shy coastal dolphin.

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Indo-Pacific Humpback Dolphins (*Sousa chinensis*) in Shoal Bay, Darwin Harbour.
Dates: October 2010 (above); October 2011 (below). (Carol Palmer)

New island records of *Eucalyptus alba sensu lato* for Damar and Romang, Lesser Sundas, Indonesia

Colin R. Trainor

School of Environmental and Life Sciences, Charles Darwin University,
Darwin NT 0800, Australia. Email: halmahera@hotmail.com

Abstract

Eucalyptus alba sensu lato is currently distributed through northern Australia and Papua New Guinea, as well as the Lesser Sunda islands of Indonesia and Timor-Leste. In the Lesser Sundas the distribution of *E. alba* is poorly-known, but it has been recorded from the central islands of Flores, Solor, Adonara, Lembata, Pantar, Alor, Atauro, Wetar and Timor. Here, I document the first *E. alba* records for two remote volcanic Lesser Sunda islands - Damar and Romang. I also note new *E. alba* records from the less isolated Lesser Sunda islands of Lirang, Leti and Moa. Further study of these populations is needed to clarify the relationships, taxonomic status and dispersal among members of the *E. alba* species complex.

The occurrence of eucalypts growing naturally outside Australia is relatively poorly known. About 15 species grow outside Australia, and four species are known from Wallacea. On Sulawesi, the dominant oceanic island in the Wallacean realm, *E. deglupta* is a tall forest species. In the Lesser Sundas, three *Eucalyptus* species are currently recognised. The Lesser Sundas comprises hundreds of oceanic islands in southern Wallacea (south of Sulawesi and Maluku) but is dominated by Lombok, Sumba and Sumbawa in the west and Flores, Alor, Timor, Wetar and the Tanimbar archipelago in the central and eastern parts (Figure 1). In the hills, *Eucalyptus urophylla* occurs locally on Flores through to Wetar and Timor. The Wetar form of *E. urophylla* was split into *E. wetarensis* (Pryor *et al.* 1995), but recent genetic work includes it within the *E. urophylla* complex (Payson *et al.* 2007). On Timor's highest peak, Mount Ramelau (2,963 m), *E. orophila* was collected and described as a new species (Pryor *et al.* 1995). The third Lesser Sunda *Eucalyptus* species is *E. alba sensu lato*. This is typically a tree of drier lowland habitats where it displays a high degree of variability in growth form, leaf and fruit morphology. It can grow as a woodland tree of 3–15 m or up to a tree of 50 m tall (Martin & Cossalter 1976).

The taxonomy of the *E. alba* group both in Australia and Lesser Sunda Islands remains unclear and species recognition and identity have changed regularly (Blake 1953; Pryor *et al.* 1995; Slec *et al.* 2006). The current taxonomy of this group is largely based on the size of adult leaves, buds and fruit and needs further investigation, particularly by genetic comparison. Slec *et al.* (2006) note that in

Australia, *E. alba* var. *alba*, *E. bigalerita*, *E. platyphylla* and *E. tintinnans* are all morphologically very similar and may be better treated as one variable taxon. However, they largely avoid discussing extra Australian variation. Interestingly, Indonesian taxonomists refer to Lesser Sunda populations of *E. alba* as *E. platyphylla* (Martin & Cossalter 1976). Samples of *E. alba sensu lato* from Timor with broad, deltoid leaves and large fruit would key out to *E. bigalerita* or *E. platyphylla* using Australian taxonomic keys, although they lack the orange bark of at least the former (I. Cowie pers. comm.). Blake (1953) included *E. platyphylla* and *E. tintinnans* in his concept of *E. alba* but recognised *E. bigalerita*. He gave Timor, Flores, Solor and southern New Guinea as the extra Australian distribution of *E. alba* based on specimens seen by him, and this is the broad distribution recognised in this note. From his discussion it is likely that the southern New Guinea material seen by him would currently be placed in *E. platyphylla* (I. Cowie pers. comm.).

The most comprehensive Lesser Sunda review of *Eucalyptus* was by Martin and Cossalter (1976). They described the distribution of *E. alba* as “most of the islands which lie between Bali and Wetar”, including Bali, while more recent information suggests that the western limit is the eastern tip of Flores about the active Lewotobi volcano (Trainor & Lesmana 2000). There are no records of *Eucalyptus* from Komodo, Sumbawa, Sumba or Lombok. Eucalypts are also absent from the continental island of Aru to the direct east of the Lesser Sundas (Hope & Aplin 2004), and from the extensive Tanimbar archipelago to the east of Damar (Monk *et al.* 1997). Payn *et al.* (2007) stated that *E. alba* co-occurs with *E. urophylla* on Timor, Wetar, Flores, Adonara, Lomblen (Lembata), Pantar and Alor, which is essentially the same set of islands mentioned by Martin and Cossalter (1976) (Figure 1). Martin and Cossalter (1976) stated that “the existence of *E. alba* is also probable on the islands to the east of Wetar, but as for the delimitation of the natural habitat of *E. urophylla* one here comes up against the lack of botanical knowledge of the region”. Incidentally, photos of an *E. alba* woodland on Atauro island (between Timor and Wetar) have been published (Trainor *et al.* 2007, p. 44) but there has been no specific survey for *Eucalyptus* in these islands.

This article describes the presence of *E. alba* on Damar and Romang islands. Both are part of the Inner Banda Arc, lying c. 640 km northwest of Darwin, Australia, 195 km and 85 km northeast of Timor, respectively (Figure 1). Geology on both is dominated by recent volcanics, with raised coralline limestone along the coasts and inland. No weather stations exist locally on Damar, but rainfall on Romang Island averages at least 2,518 mm/year. Damar is a relatively high rainfall island, but the coasts are dry (c. 1200–1600 mm/yr) and rainfall tends to increase with elevation (RePPPProT 1989). Approximately 75% (c.150 km²) of the island retains closed-canopy tropical forests (projective foliage cover >70%: Specht *et al.* 1974), including dry forest near the coast with many deciduous trees (to 12–20 m tall), grading into semi-evergreen and evergreen forest further inland (to 40 m tall), above c.60 m elevation (Trainor 2007).

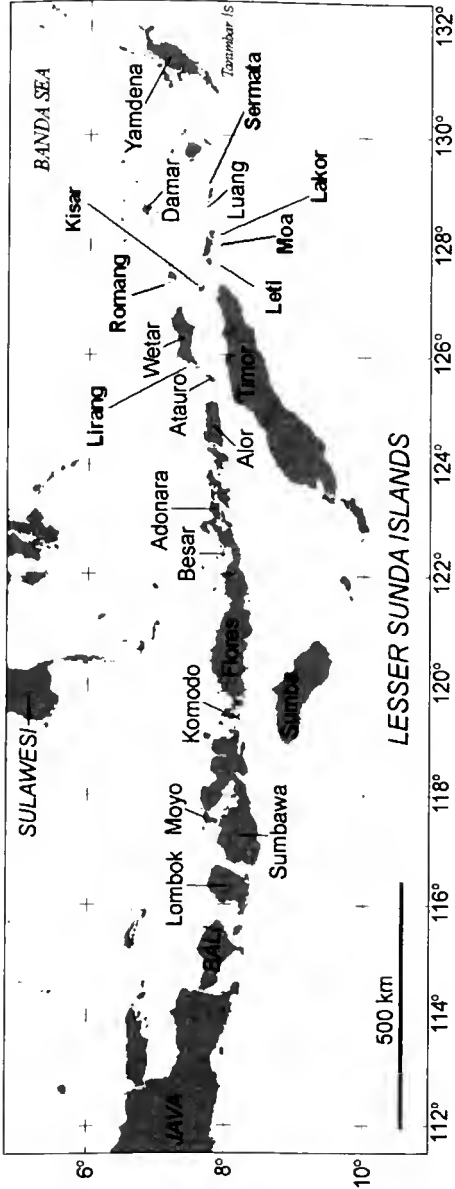


Figure 1. Location of Lesser Sunda islands mentioned in the text.

Forest is used for conversion to smallholder agricultural plots, timber collection and moderately intensive hunting of pigs, and birds (Trainor 2007). I also briefly mention the occurrence of *E. alba* for a further six Lesser Sunda islands (Lirang, Kisar, Leti, Moa, Lakor and Sermata: Figure 1). These islands are all less isolated from the potential *Eucalyptus* source islands of Timor and Wetar, but there has been no previously published information on the status of *E. alba* on them, as far as I am aware.

I visited Damar Island for about 4 hrs on 19 August 2008 while en-route to Wetar Island from Saumlaki, Tanimbar archipelago. Observations from a small “perintis” ship of a distinctive vegetation formation on ridges behind Wulur village (the main village on the island with about 300 houses) appeared to be of *Eucalyptus*, so I investigated further and took photos of trees, leaves and fruit. During a previous visit in 2001 (Trainor 2007), I walked about 100 km over 30 days throughout most of Damar except the south coast, visited two offshore islets, but did not observe any *Eucalyptus*. Romang Island was visited for 14 days during October 2010, primarily to observe birds, with briefer visits to Kisar (9 days), Leti (6 days), Moa (sailed past only in 2001 and 2010), Lakor (docked at harbour twice and sailed past the coast in 2010) and Sermata (8 days) in October–November 2010. I sailed past Lirang Island, 2.9 km southwest of Wetar, in 2001 and on 9 November 2008.

Damar Island

On Damar, *E. alba* grew on ridges directly behind Wulur village (Figure 2), with trees starting at about 30 m elevation up to at least 300 m on quite steep slopes. The trunk was upright and smooth with a yellow-orange colour, and grew to about 12 m (Figure 3). The leaves appeared small (they were not measured); they were alternate and ovate, the fruit were obconic, disk annular, rims slightly exserted, valves 4, exserted (Figure 4). Within-island variation in *E. alba* morphology and growth form is substantial (e.g. on Timor: Martin & Cossalter 1976). Compared to closely related species in northern Australia such as *E. tintinnans* and *E. bigalerita* the bark appears paler (I. Cowie pers. comm.). The series of about 10 photographs from 2008 of the hills behind Wulur show many small patches – some continuous for hundreds of metres at least – of *E. alba* up to about 1 ha in extent on ridges and steep slopes. In stark contrast to the landscape patterning of *Eucalyptus* on neighbouring islands (e.g. Timor, Wetar, Alor, Pantar and Lembata) there appears to be a very indistinct boundary between the *E. alba* and surrounding vegetation, which appears (from photos) to comprise a tropical dry forest with a dense canopy cover (probably degraded through the high proximity to village).

No notes were made of the understorey beneath *E. alba*, but two photos show several tropical forest shrubs in full leaf during this mid-dry season period. The lack of a distinct *E. alba* – tropical forest boundary and presence of these shrubs, suggests that the *E. alba* woodland is being actively invaded by tropical forest. Fire regimes are an important factor in maintaining closed forest – *Eucalyptus* boundaries in tropical



Figure 2. Location of the readily visible patches of *Eucalyptus alba* woodland on steep ridges (indicated by arrows) above Wulur village, Damar island. The square shows the approximate location of the tree visited. The view is about 500 m wide and looks towards the southwest.

Figure 3. A *Eucalyptus alba* tree directly above Wulur village, Damar Island (about 50 m from the nearest house). Note yellow-orange trunk and the dense understorey of broadleaf shrubs and some weeds.



and other parts of Australia and may also be important in the Lesser Sundas. The lack of contrast with neighbouring tropical forest and indication that the *E. alba* woodland is being invaded by tropical forest makes it difficult to identify or discriminate the *E. alba* woodland from a distance, and therefore it is likely to be overlooked. Conceivably, there could be many square km of *E. alba* on Damar, but the photos show an area of at least 5–10 ha over about 1% of the available ridges on the island. The photos show small patches of swidden had been cut and burnt, which appears to have been done in both the tropical forest and also in the *E. alba* woodland. Apart from the swidden, there was no evidence of fire, though I did not enter the middle of *E. alba* patches.



Figure 4. Leaves and fruit of *E. alba* above Wulur, Damar Island.

Romang Island

On Romang Island, *E. alba* grew on volcanic platforms above beach (Figure 5a), on ridges of moderate slopes similar to Damar (Figure 5b), and on inland plateaux in a complex mosaic with regenerating gardens and secondary forest. In this latter situation the small patches of *Eucalyptus* appeared to have not been converted to swidden agriculture because they occurred on rocky terrain (limestone) with heavy soils that are probably marginal for agriculture. Leaf shape of *E. alba* on Romang was ovate (Figure 6). *Eucalyptus* is not listed for Romang Island by one of the few reports on trees covering the Banda Sea islands (Hilderbrand 1951)

Other Islands

The Outer Are islands of Kisar, Leti, Moa, Lakor and Sermata are primarily low, dry limestone islands which provide a striking contrast to Damar and Romang. Kisar lies 25 km north of Timor and is dominated by lontar palm *Borassus flabellifer* savanna but *E. alba* was absent. On Leti, 38 km east of Timor, *E. alba* was a dominant tree in the lowlands (Figure 5), though is heavily used for firewood. On Moa, *E. alba* was visible

on a photo (slide) taken while sailing past the island in 2001 – but during the recent visit I travelled past the island at night only. The steep and dry slopes of Lirang Island, of the Inner Banda Arc, were dominated by *E. alba* with tropical forest in gullies and higher slopes above extensive mangroves (Figure 5d). No *Eucalyptus* was observed on the flat coralline island of Lakor (directly east of Moa), or on Sermata (a wetter limestone island).

Formerly, *E. alba* in the Lesser Sundas was known from eight islands, with a further five islands added here. Genetic diversity of *E. urophylla* was shown to decline from east towards the west which gave clues to the colonisation history of that tree



Figure 5. Island landscape views of *Eucalyptus alba*: (a) *E. alba* (to 10 m tall) in a typically narrow band backed by tropical forest above rocky volcanic cliffs on Romang; (b) Extensive patches of *E. alba* forest (to 25 m tall) on Romang with a grassy understorey on ridges and slopes, with adjacent slopes and gullies dominated by evergreen tropical forest – note dense canopy cover; (c) *E. alba* (to 15 m tall) dominates the steeper hills behind a village on Leti, with tropical forest in gullies and higher slopes, but much of the coastal strip has been converted to coconut plantation; (d) Sparse stands of *E. alba* (to 10 m tall) dominates the steep lower slopes and ridges on Lirang Island, late dry season.

in the Lesser Sundas (Payn *et al.* 2007). For *E. urophylla*, Payn *et al.* (2007) suggested that long distance island colonisation events were probably assisted by sea currents. An investigation of the genetics of both remote (Damar and Romang) and less remote island populations of *E. alba* might also provide interesting insights into the colonisation history and taxonomic status of this eucalypt on islands just off continental Australia.

Acknowledgements

The visit to Damar, Wetar and Lirang was supported by Jon Walker of Columbidae Conservation, and my Romang visit was given logistical and transport support by P. T. Gemala Borneo Utama. Don Franklin gave helpful guidance and comments during the preparation of this note. Thanks to Ian Cowie for reviewing this article, providing references and additional information on the *E. alba* complex.



Figure 6. The ovate leaf form of *E. alba* on Romang island, with a White - shouldered Triller *Lalage sueurii* (Romang form), a common component of open habitats on the island.

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Short-tailed Shearwater *Ardenna tenuirostris* in the Northern Territory

Peter M. Kyne¹ and Micha V. Jackson²

¹ Tropical Rivers and Coastal Knowledge, Charles Darwin University,
Darwin NT 0909, Australia. Email: peter.kyne@cdu.edu.au

² North Australian Indigenous Land and Sea Management Alliance, Charles
Darwin University, Darwin NT 0909, Australia.

Abstract

The Short-tailed Shearwater *Ardenna tenuirostris* is a trans-equatorial migrant seabird that breeds in the austral summer in southern Australia (principally in Tasmania and Victoria, with smaller numbers breeding in New South Wales, South Australia and southern Western Australia) (Marchant & Higgins 1990). Post-breeding, the species migrates to the north Pacific where non-breeding colonies stay during the months of May–September (Marchant & Higgins 1990). This is Australia's most abundant seabird, population estimate 13.1–16.5 million breeding pairs (Ross *et al.* 1996), and can be seen in considerable numbers off eastern and southern Australia during migration and the breeding season. Migrating birds are regularly recorded from Tasmania to south-eastern Queensland (Marchant & Higgins 1990), but do not generally occur in tropical northern Australian waters. We report the first confirmed record of Short-tailed Shearwater in the Northern Territory, and one of the few tropical Australian records of the species.

Between approximately 1820 and 1845 on 14 January 2011, a Short-tailed Shearwater was observed and photographed from Stokes Hill Wharf, Darwin Harbour, Darwin, Northern Territory (12°28'16"S, 130°50'54"E) (Figure 1) by the authors and three other local birdwatchers. The bird was initially sighted on the water, where it remained for the majority of the observation period. It took flight only once, over a short distance (approximately 20 m). At times the bird was very close to the wharf and was observed and photographed from above. It stretched its wings once, allowing views of the underwing. The remiges and rectrices were noted to be worn. Towards the end of the observation period it slowly swam/drifted in a south-easterly direction into Darwin Harbour and was out of sight by approximately 1845 h. Visits to the same location on the evenings of 15 and 16 January 2011 could not relocate the bird.

Stokes Hill Wharf consists of an old shipping shed that has been converted into a series of food outlets and outdoor eating areas and is a popular dining location, particularly on weekends. A number of birds, in particular Silver Gulls *Chroicocephalus novaehollandiae* and Crested Terns *Thalassens bergii*, are attracted to the wharf, as diners



Figure 1. Short-tailed Shearwater *Ardenna tenuirostris*, Stokes Hill Wharf, Darwin Harbour, 14 January 2011. Note the darkish legs and feet and the short, rounded tail with the wing projecting beyond the tail in the top photo, and the pale underwing in the bottom photo. (Micha V. Jackson)

often distribute their leftover food (primarily hot potato chips and deep-fried seafood) to birds. The Short-tailed Shearwater was observed on a Friday evening when a large crowd of diners was present, and food was being made available to birds regularly. In addition to Silver Gulls and Crested Terns, two Common Terns *Sterna hirundo* and six Bridled Terns *Onychoprion anaethetus* were also present during the observation period; the Short-tailed Shearwater appeared to be actively feeding on the water's surface amongst these other species. One juvenile Lesser Frigatebird *Fregata ariel* was also flying low overhead.

The bird was identified as a Short-tailed Shearwater by its overall brownish plumage with a paler grey underwing panel and pale chin and throat; short, rounded tail; darkish legs and feet; rounded head profile; and relatively short, stubby bill (Marchant & Higgins 1990; Onley & Scofield 2007; Shirihai 2007) (Figure 1). Features separating it from the Wedge-tailed Shearwater *Ardenna pacifica* include the darkish legs and feet (fleshy-white to pale pink in Wedge-tailed Shearwater), pale grey underwing panel (all dark in Wedge-tailed Shearwater), short, rounded tail (long and wedge-shaped in Wedge-tailed Shearwater), and shorter bill (Marchant & Higgins 1990; Onley & Scofield 2007). Furthermore, on the water, the primary projection extended noticeably beyond the tail (Figure 1). Short-tailed Shearwaters are also bulkier with narrower, straighter wings than Wedge-tailed Shearwaters (Marchant & Higgins 1990; Onley & Scofield 2007). Features separating this bird from the Sooty Shearwater *A. grisea* include the less extensive and pale greyish underwing panels (typically more extensive silvery-white underwing panels in Sooty Shearwater), the more rounded head and higher forehead (rather than the flat-headed appearance of Sooty Shearwater), and the shorter, stubbier bill (Onley & Scofield 2007; Shirihai 2007).

There are few confirmed tropical Australian records of Short-tailed Shearwaters, and none from the Northern Territory (Marchant & Higgins 1990; Barrett *et al.* 2003). The species is a vagrant to northeast Queensland, with records north to Cairns (16°55'S, 145°46'E) (Baker & Gill 1974; Longmore 1985; Marchant & Higgins 1990), and one record from north of Lockhart River on Cape York Peninsula (~12°40'S, 143°24'E) (Barrett *et al.* 2003). In northwest Western Australia, there is a single record of a beach-washed bird on Cable Beach in Broome (17°55'S, 122°12'E) (Hassell 1999) and sightings of four birds at sea in Joseph Bonaparte Gulf (C. Hassell, pers. comm.). The Darwin observation represents the first confirmed record of the species for the Northern Territory. However, Noske and Brennan (2002) reported two probable Short-tailed Shearwaters from Groote Eylandt in the Northern Territory sector of the Gulf of Carpentaria. These birds were located on Six Mile Beach, Groote Eylandt (13°56'S, 136°47'E) on 8 May 1999; one bird was dead but the specimen was not retained, while the other bird was rehabilitated and released on 13 May 1999 (Noske & Brennan 2002). Noske and Brennan (2002) present a photograph of the rehabilitated bird, and comment that '... its large size, short tail, dark legs and short, dark bill ...' suggest Short-tailed Shearwater. Although likely to represent records of Short-tailed Shearwaters, the lack of additional photographs, descriptions

and measurements, and the disposal of the dead specimen, preclude certain identification.

The only other all-dark shearwater to have been previously recorded in the Northern Territory is the Wedge-tailed Shearwater, a tropical species that has been documented on several occasions in coastal waters around Darwin during monsoonal storm events in the months of January and February (McKean & Gray 1973; McKean *et al.* 1975; Thompson 1977). Similarly, many of the records of Short-tailed Shearwater from northern Australia (Baker & Gill 1974; Longmore 1985; Hassell 1999; C. Hassell, pers. comm.; this manuscript) have been associated with intense tropical weather systems. The northwest Australian Short-tailed Shearwater record and sightings coincided with weather associated with tropical cyclones, with the record of the Broome bird in December and the Joseph Bonaparte Gulf sightings in February (Hassell 1999; C. Hassell, pers. comm.). Consistent with these observations, the Darwin Short-tailed Shearwater record occurred during a period of monsoonal storms with strong onshore winds. These conditions had pushed several infrequently-occurring seabirds into Darwin Harbour, including large numbers of Lesser Frigatebirds and moderate numbers of Bridled Terns (pers. obs.). These weather conditions commenced on 11 January 2011 and had dissipated by 15 January 2011.

Even though the Short-tailed Shearwater is primarily a migratory species of the Pacific Ocean, there has been suggestion of regular movements to the northern Indian Ocean, although these remain poorly understood (Marchant & Higgins 1990; Hassell 1999). The sighting of the Darwin individual in January, which is outside the usual migration period for the species, suggests that this individual probably was not undertaking a normal seasonal movement to the northern Indian Ocean. Given the abundance of this species and its highly migratory nature, it is not surprising that it should occur, on occasion, outside its normal distribution.

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Waiting for the wet: out-of-season records for adult Leichhardt's Grasshopper *Petasida ephippigera* (Orthoptera: Pyrgomorphidae)

Peter Holbery

GPO Box 929, Darwin NT 0801, Australia.

Email: peter.holbery@immi.gov.au

Abstract

A number of adult Leichhardt's Grasshopper *Petasida ephippigera* White, 1845, were recorded in July, about two months earlier in the year than they are usually observed. This early adult phenology may have been the result of unusually high rainfall experienced during the preceding wet season. It was also noted that all developmental stages of Leichhardt's Grasshoppers were more often found on less vigorous shrubs of their food plants, *Pityrodia* spp.

Introduction

The brightly-coloured Leichhardt's Grasshopper *Petasida ephippigera* (Figure 1) is a striking insect of the Top End, though few people have actually seen it in the wild. The species occurs in scattered localities north of 16°S in western and northern Arnhem Land and in the eastern Kimberley-western Victoria River District (Calaby & Key 1973; Lowe 1995; Wilson *et al.* 2003). Leichhardt's Grasshopper usually lives in close association with various species of *Pityrodia* (Lamiaceae) that comprise its main food plants, but it has also been found in association with *Gardenia* (Rubiaceae) and *Dampiera* (Goodeniaceae) (Key 1985).

Available information on the life cycle of Leichhardt's Grasshopper indicates that eggs hatch early in the dry season and adults mature by the onset of the wet season (Key 1985). Juveniles have been recorded from May to November, while adults have been recorded from September to April.

Observations

During the past three years (2009-2011) intermittent observations were made along the Barrk Walking Track at Nourlangie Rock in Kakadu National Park. Leichhardt's Grasshoppers were found at three sites along this track on the sandstone plateau. At the first site, the only observation was of a single adult female in January 2009, although the site contained an extensive patch of *Pityrodia jamesii*.



Figure 1. The brightly-coloured Leichhardt's Grasshopper *Petasida ephippigera* on its food plant *Pityrodia jamesii*. (M.F. Braby)

At the second site, only a single juvenile was sighted, in July 2011. This individual was an early instar nymph that was located on *P. jamesii*. Only a few of these food plants were present at the second site, and all were small in stature.

At the third site, Leichhardt's Grasshoppers were observed on every visit, except for one occasion in June 2009. Nymphs were usually present in the dry season, while adults were recorded mainly in the wet season (December-April); however, during the 'build-up' both juveniles and adults were present. The third site had an abundance of large *P. jamesii*, but Leichhardt's Grasshoppers were never found on these plants. Instead, they were always found on a smaller and apparently different species of *Pityrodia*, most likely *P. puberula* (P. Barrow & D. Franklin, pers. comm.). During June

2009, all the *P. puberula* plants at this site were withered and appeared dead, although they recovered later in the season. However, a number of juveniles and some adults were present at the third site when I visited the area during the 'build-up' in October 2009, indicating remarkable resilience to poor food quality.

During a visit to the third site on 31 July 2011, numbers of Leichhardt's Grasshoppers were observed. Most of these grasshoppers comprised early instar nymphs, but surprisingly four adults were present. An adult female and an adult male were on two separate shrubs and a pair was on a third shrub. Each adult was perched on a separate twig of *Pityrodia puberula*. All individuals were in perfect condition, and absence of missing limbs or wing damage suggested that they had moulted recently.

On 1 August 2011, observations were made at a fourth site in Kakadu National Park, along a road about 3 km from Gubara Pools, to ascertain whether any adult Leichhardt's Grasshoppers were present. This site is some distance from Nourlangie Rock and only *P. jamesii* was found there. Large numbers of early instar nymphs were present, as well as two individuals that were more developed. Based on the photographs in Rentz *et al.* (2003), one of the large nymphs appeared to be in the third instar, while the second one appeared to be in the fourth instar. No adults were present at this site.

Discussion

Leichhardt's Grasshoppers were usually observed on smaller and less healthy-looking specimens of their *Pityrodia* spp. food plants. Vigorously-growing food plants appeared to be avoided. Wilson *et al.* (2003) made similar observations of Leichhardt's Grasshopper nymphs at Nitmiluk National Park.

These findings parallel my own unpublished observations of another grasshopper in the same family, the Southern Pyrgomorph *Monistria concinna* in southern coastal New South Wales. This species was usually found on smaller, unhealthy-looking specimens of its food plant, *Westringia fruticosa*. The Southern Pyrgomorph has been shown to be distasteful to predators (Groeters & Strong 1993). The insects may be deriving something particular from these smaller, unhealthy-looking plants, or these plants may be more palatable to the insects. It would indeed be interesting to investigate this aspect of food plant preference for related Northern Territory species, such as the Torpedo Grasshopper *Parastria reticulata*, the Painted Pyrgomorph *Greyacris picta* and the Blistered Pyrgomorph *M. pustulifera*, as well as for Leichhardt's Grasshopper.

The occurrence of adult Leichhardt's Grasshoppers in July appears to be quite unusual given previous records of the species. The early adult phenology may have been related to the preceding La Niña-induced wet season, during which rainfall was well above average. Jabiru is the nearest location to Nourlangie Rock for which rainfall figures are readily available. These data give an indication of the magnitude of

the 2010-2011 wet season in the Top End. The Bureau of Meteorology (2011a) gives a long term annual rainfall average of 1,589.40 mm for Jabiru. Rainfall in Jabiru during the most recent wet season (October 2010-April 2011) was 2,422.60 mm (Bureau of Meteorology 2011b). In other words, rainfall during these seven months at Jabiru exceeded the average annual amount by 833.2 mm.

Above-average rainfall and the pronounced wet season may have resulted in a longer growing season for Leichhardt's Grasshopper food plants. This in turn may have resulted in better quality nutrition for the insects, enabling them to mature earlier than usual. The food plants at the third site were certainly in better condition in July 2011 than they were in June 2009, when the plants were withered and appeared dead. Thus, better food quality in 2011 probably allowed adults to mature as early as July, unlike in other years when adults do not normally appear until September or later.

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Book Review

Stray Feathers: Reflections on the Structure, Behaviour and Evolution of Birds

By Penny Olsen and Leo Joseph. CSIRO Publishing, Collingwood. 2011; 286 pp; paperback. ISBN: 9780643094932. Price A\$59.95.

Richard Schodde introduces this book by stating that knowledge of the *what* and the *where* of Australia's birdlife abounds, but we know very little about the *how*: how they move, feed and have evolved their life forms. '*Stray Feathers*' focuses on the how, and it was this approach that enticed me to buy a copy.

This book's genesis is based on illustrations intended for another book that never eventuated. The current authors have opportunistically written short essays to accompany these illustrations and discuss some interesting adaptations of Australia's bird species. The book is organised by theme, such as Anatomy and Physiology, The Senses, Giving Voice, Plumage, Getting Around, Finding and Handling Food, Using 'Tools', Communicating, Courtship, Nests and Parental Care, with about 3 – 10 short sections in each. Each section is one or two pages long, including beautiful black and white line drawings, and uses one species (or closely related species) to illustrate a behaviour or adaptation. There is no index or even an alphabetical list of the names of the species included in the book.

The authors obviously know their subject matter very well, and have done a good job of amassing information on a large range of species, including many lesser known ones. It would be almost impossible not to present lots of fascinating information in a book about evolutionary adaptations in birds, and this is certainly the case for '*Stray Feathers*'. Here is a sample of what I found most interesting:

- The complexity of a bird's jaw and bill, which allows precise manipulations of their food.
 - Birds process heavy food quickly to minimise weight during flight (e.g. the average passage times in fruit eaters are 15 to 60 minutes). Birds have evolved mechanisms to remove water from food about 10 times faster than mammals on similar diets.
 - Have you ever wondered how such small birds can make such loud calls? In birds, sounds are made using nearly all the air passing through the respiratory system, compared with humans, who use only about 2% of inhaled air to speak.
 - Parrots have relatively simple vocal organs, and their talking ability stems from their versatile spoon-shaped tongue.
-

- Treecreepers climb trees from bottom to top, while sitellas spiral head-first from top to bottom. Both have the anatomical adaptations appropriate to their way of moving.
- The wedge-tailed eagle weighs only 3-4 kg, yet its grip is 10 times more powerful than that of the human hand.
- Most Territorian naturalists would have heard about black kites using fire to help with their hunting. However, they may not know that kites have also been observed to drop bread scraps into a river to attract fish to the surface.
- Boobies don't have a brood patch (a highly vascularised, bare-skinned patch that transfers heat from parent to egg), but instead curl their large, fleshy feet over their eggs to keep them warm.
- Australian swiftlet parents often lay a second egg after the first egg is hatched. The first chick incubates this second egg, even developing a brood patch. No other bird is known to use such a strategy, one that seems very sensible to me!

The authors say that the book "is intended as a 'taster' for bird lovers or students who wish to gain some insight beyond a simple enjoyment of birds", but the style sits uneasily between the technical and the popular. Thus, while the concept is inherently appealing to popular audience, the style is often turgid and academic, and full of difficult technical terms that only an expert would understand. For example, the first sentence in the piece 'Swimming on land: Short-tailed Shearwater' is: "On the ground most procellariids shuffle along on their tarsi (legs)." A lay reader is just left to assume that the procellariids include shearwaters – but what else? It then says that shearwaters have "backwardly placed legs" – what are these exactly? It does not explain, and again I was left feeling vaguely unsatisfied. There are numerous instances where an idea is inadequately explained, and the illustrations, while lovely, could do with more detailed captions to help explain the point the text is trying to make. In addition, unless you are very familiar with Australian bird species, you will probably want to read this book together with your favourite bird ID book, so you can get some more general background about each species – especially simple distribution maps. The lack of an index is a serious drawback if you want to use it as a reference book. Most of all, this book would have greatly benefitted from an editor experienced in communicating science, which would have boosted its appeal to a general audience.

Overall, I was a little disappointed in this book. While there is much to commend it, it is not as good as it could be. The wonderful adaptations of birds deserve to be communicated in a more engaging way to the general public.

Lynda Prior

School of Plant Science, University of Tasmania

Email: lynda.prior@utas.edu.au

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